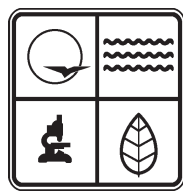


TOPICS IN WATER USE: SOUTHERN MISSOURI



Integrity and excellence in all we do



MISSOURI DEPARTMENT OF NATURAL RESOURCES
Geological Survey and Resource Assessment Division

Mimi R. Garstang, Director and State Geologist

P.O. Box 250, Rolla, MO 65402-0250

Phone: (573) 368-2100 FAX: (573) 368-2111

e-mail: www.dnr.mo.gov/geology

***Cover:** Lower outlet of Big Spring in Carter County, Missouri. Photo by Susan C. Dunn*

Library of Congress Catalog Card Number: 2003108876
Missouri Classification Number: MO/NR Ge9:63

Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, 2003,
Topics in Water Use: Southern Missouri, Missouri Department of Natural Resources, Geological
Survey and Resource Assessment Division, Water Resources Report Number 63, 90 p., 17 figs., 4 tbls.

As a recipient of federal funds, the Missouri Department of Natural Resources cannot discriminate against anyone on the basis of race, color, national origin, age, sex or handicap. If anyone believes he/she has been subjected to discrimination for any of these reasons, he/she may file a complaint with either the Missouri Department of Natural Resources or the Office of Equal Opportunity, U.S. Department of the Interior, Washington, DC, 20240.

Table of Contents

	Page
1. INTRODUCTION	1
The Regional (Economic-Environmental-Social-Political Boundary) Approach	1
Economic Overview	3
Watershed Based Approach	3
Temporal Aspect of Water Use	4
2. ACKNOWLEDGMENTS	5
3. REGIONAL DESCRIPTION	7
Southeastern Missouri Regional Description	7
Colleges and Universities	7
Regional Transportation	7
Population Characteristics	9
Industry, Commerce and Agriculture	13
Physical Characteristics	13
Recreation	16
Southwestern Missouri Regional Description	17
Colleges and Universities	17
Regional Transportation	20
Population Characteristics	20
Industry, Commerce and Agriculture	24
Physical Characteristics	24
Recreation	26
4. REGIONAL WATER USE OVERVIEW	29
Southeastern Regional Water Use Overview	29
Water Resources Management	29
Public Water Supply	31
Domestic Water Use	31
Industrial and Commercial Water Use	31
Agricultural Water Use	32
Water Use in Power Production	32
Other Instream Flow Uses	33
Southwestern Regional Water Use Overview	34
Water Resources Management	34
Public Water Supply	34
Domestic Water Use	34
Industrial and Commercial Water Use	35
Agricultural Water Use	35
Water Use in Power Production	35
Other Instream Flow Uses	36

5. WATER USE PROBLEMS	37
DRINKING WATER USE	37
Groundwater Assessment Needed	37
Overuse of Groundwater in Site Specific Areas	39
Unplugged Abandoned Wells	44
Private Water Well Construction and Water Quality	45
Seismic Activity	49
Aging Infrastructure of Public Water Supply Systems	50
True Cost of Water	50
Inefficient Water Use	51
Lack of Water Rights Laws	52
AGRICULTURAL WATER USE	54
Improper Land Application of Poultry Litter	54
Fish Farming	55
INDUSTRIAL WATER USE	57
Effects of Metallic Mineral Mining	57
Industrial Pollution	57
Building in Flood Plains	58
Dam Operations	60
RECREATIONAL WATER USE	62
The Condition of Water Can Affect Tourism	62
Watershed Conservation and Land Use	63
Pathogenic Coliform Bacteria in Streams	64
National Scenic Rivers	65
Problems Associated with Recreational Uses	65
Problems Associated with Water Allocation	67
ENVIRONMENTAL WATER USE	68
Population Dispersion	68
Stormwater Runoff	69
Introduction of New Chemicals into Use	70
Endocrine Disrupters and Water Pollution	72
Coal	74
Landfills and Dumps	74
Gravel Mining	75
Deforestation	77
Water and the Ability of our Plant Life to Help Keep it Clean	78
Altered Watercourses in the Bootheel	79
Governmental Agencies Coordination	80
6. WATER USE OPPORTUNITIES AND REGIONAL OBSERVATIONS	83
Long Range Studies	83
Water Efficiency Makes Good Economic Sense	84
Sustainable Groundwater Resources	84
Dry Hydrants	85
Rainwater Capture	86
Bootheel Area Multifunctional Wetlands	86
7. COMMENTS RECEIVED	89

List of Figures

Figure	Page
1. Counties covered by each regional report	2
2. Map showing counties of southeast Missouri region covered by this report	6
3. Locations of colleges and universities in southeast Missouri	8
4. Railways and river ports in southeast Missouri	10
5. Major roads and cities in southeast Missouri	12
6. Missouri average annual precipitation from 1971-2000	14
7. Physiographic provinces of Missouri	15
8. Map showing counties of southwest Missouri region covered by this report	18
9. Locations of colleges and universities in southwest Missouri	19
10. Railways in southwest Missouri	21
11. Major roads and cities in southwest Missouri	22
12. Freshwater-salinewater transition zone	25
13. U.S. Forest Service acres in southern Missouri	30
14. Idealized “cone of depression” from pumpage of a high-yield well	40
15. Groundwater-level hydrograph, Noel observation well, McDonald County	43
16. Map showing drilling areas for private well construction regulations	46
17. Private water well test results from U.S. Centers for Disease Control, 1994 study	48

List of Tables

Table	Page
1. Southeast Missouri region counties and their population	11
2. Number of state and federal recreational facilities in southeast Missouri	16
3. Southwest Missouri region counties and their population	23
4. Number of state and federal recreational facilities in southwest Missouri	26



Introduction

According to the Missouri Water Resources Law (sections 640.400 to 640.435, RSMo), the state water resources plan is to address water needs for the following uses: drinking, agriculture, industry, recreation and environmental protection. Addressing water “needs” requires us to establish why these needs exist in the first place. In some cases, an existing water need is tied to one or more unresolved water problems. For example, communities “need” clean water. To meet this need, communities may have to address problems with water supply infrastructure, adequate quantity and, at the same time, source water quality. This report takes a step toward addressing the water needs of southern Missouri by identifying problems it faces.

As noted in the legislation, there are many aspects of water use problems. Missouri water law is concerned both with protecting private individual water rights and protecting the public health and welfare. In addition to social and economic needs, there are the environmental needs of forests, fish and wildlife of Missouri. There are the facets of quantity and quality of the water resources, themselves. And there are the political jurisdictions that administer public water supplies under Missouri statutes. It is within this matrix of considerations that we have approached these regional water use problems and opportunities as well as the broader topic of State Water Planning.

To ensure equal consideration for all uses, emphasis was placed on identifying water use problems in each topical area identified in the Water Resources Law. Similar topics sometimes are addressed in more than one category, reflecting the different viewpoints of those who raised these topics as water use problems.

When reading the water use problems identified in southern Missouri, it will become apparent that many of them are, in fact, very closely related. In addition, because of the diverse perspectives the various contributors bring to this effort, what, from one standpoint, may appear to be a “serious problem,” may not seem so, from another. For these reasons, the following problems underscore the importance of working cooperatively in addressing the water use problems facing southern Missouri.

The Regional (Economic-Environmental-Social-Political Boundary) Approach

Water resource professionals commonly subdivide the state into physiographic units, such as watersheds or aquifers. While this approach is important for resource-based discussions, it inadequately addresses water use problems. While the water supply side is chiefly focused on where the water resource is located, its quantity and quality, the water use side is focused primarily upon administering demands, needs, and the purposes the water serves. In this series of reports, we have chosen to address the subject using the broad geographic similarities of the six field service areas of the Department of Natural Resources. This volume is the fourth in the series of five reports that will cover the entire state. As of June, 2003 the Missouri Department of Natural Resources has reduced its field offices from six to five. This has resulted in



an increase in the number of counties that each remaining field office services. But, for the purpose of this series of reports the traditional service areas will still be used to complete the remaining reports. Figure 1 shows the areas covered by each of the regional reports. Each of these regions has distinctive physiographic features and socio-economic characteristics, as well as being composed of counties, and therefore was chosen for the ease of referencing water use problems. This approach allows us to recognize Missouri's diversity, and lends itself well to Phase 2 of the State Water Plan.

The areas served (pre-June, 2003) by the department's Southwest and Southeast Regional Offices in Springfield and Poplar Bluff are the focus of this report. These two regions of Missouri are mostly identified as the Ozarks and the Bootheel region of the state. Staff members of these two offices and of other state agencies dealing with water resources were the primary sources of information for this effort. This enables us to draw upon the insights and experiences of field staff who, by virtue of their work, deal with many water use problems facing residents of southern Missouri on a daily basis.

Economic Overview

For Missouri as a whole, agriculture, tourism, and manufacturing are the three major industries. Formerly more significant than today, mining has a long history in the region and has the potential for future significance as a basic industry.

For Southern Missouri, agriculture is the primary industry, in a state that ranks among the top producers in the nation. Southwestern Missouri is principally known for poultry production, even though it also is a top producer of beef, and southeastern Missouri is principally known for such southern crops as cotton, rice, and watermelons, even though it is a producer of corn, wheat, soybeans, and orchard fruits. Meatpacking, especially poultry, increases the value of the agricultural economy in the region.

Southwestern Missouri is the home of Branson, one of the live music capitols of the world and one of the top tourist destinations in

the U.S. Headliner entertainers, especially musicians, make their homes in Branson, where their theatres host thousands of patrons daily. The counties that showed the greatest population growth, as measured in the 2000 census, were Christian, Stone, and Taney Counties, all of which gained more than 50 percent. Branson is in Taney County, Christian and Stone Counties lie just to the North and West of Taney County. Other popular tourist attractions include Table Rock Lake and other Corps of Engineers reservoirs, numerous state parks, and fabulous fishing. Canoeing, most often in the form of float trips, is one of the important tourism industries. The Ozark National Scenic Riverways, including the Current River and Jack's Fork, in southern Missouri, abundant water resources and the aesthetically beautiful setting of the Ozarks are also principal tourist draws.

The manufacture of aluminum boats and canoes is a big industry in the region. Names such as Osage Canoes, Bass Tracker Boats, Landau Boats, Ranger, and Lowe, all in the greater Lebanon area, have easy access to Interstate Highway 44. The Bass Pro Shop's Outdoors Missouri complex in Springfield is also a major tourist draw. Southern Missouri is a hunter's, floater's, fishermen's, and equestrian's paradise with many acres of national forest land and exceptional lakes and waterways.

The Watershed Based Approach

The watercourses of the southern Missouri region drain either directly or indirectly into the Mississippi River. Those of southeastern Missouri drain to either the Diversion Canal or the Mississippi, except for those that drain to the St. Francis River or the Black River. Those of southwestern Missouri drain to the Arkansas River by way of either the White River or the Grand River. North of Springfield, the watercourses drain toward the Osage River, which flows into the Missouri River. Rising near Hartville, the seat of Wright County, the Gasconade River flows northeasterly into the Missouri River.

Watersheds may be defined as the areas of land that drain surface water runoff into a central watercourse. The watershed usually is named after its stream, such as the St. Francis River Watershed. In the 1990s, federal and state environmental planners began to put a greater emphasis on consideration of water resources and water problems within a watershed context. In this manner, they hoped to take into consideration all the factors that affect water quality, from a geographic perspective. Comprehensive watershed assessment, planning, and management of water resources makes sense, but political boundaries (cities, counties, states) rarely follow watershed boundaries. Indeed, boundaries often follow watercourses, effectively dividing any watershed where this occurs. Therefore, cooperation and coordination among all the jurisdictions within any watershed is critical to taking a watershed approach to the solving of problems like nonpoint source pollution.

Concerning this watershed based approach, segments of the separate watersheds are further subdivided into increasingly smaller “hydrologic units” so that distinct watersheds may be broken into more manageable sizes for study. Watersheds (or hydrologic units) have been assigned identification numbers so that the several agencies working with them can be in agreement on the piece of land they are studying. There are 2-digit, 4-digit, 6-digit, 8-digit, 10-digit, and 12-digit watersheds. The more digits, the smaller the watershed identified. The watershed approach has been endorsed by leading

federal agencies like the Environmental Protection Agency and the U.S. Department of Agriculture. It should be remembered that these watersheds define surface water drainage areas only, and while interacting with groundwater areas and political boundaries, they are but pieces of the bigger picture of the interrelationships of water supply and water use.

Temporal Aspect of Water Use

Times change, and styles change. Per capita, more water is used today than ever before. Those folks who are self-supplied (mostly rural dwellers on their own wells) use much less water per capita than those on public water supply systems. Hydropower use has evolved from water wheels that turned the stones of gristmills of early Missourians to the large power generating plants of today. Bathing, clothes washing, and other occasional uses of water by Missouri’s previous generations was nothing compared to the water use demands of today’s large population of Missourians. Greater demands, in each generation, have resulted in efforts to supply ever-greater quantities of finite supplies of water to our population. Not only is it just more people using more water, but rather more people using greater quantities of water in a greater variety of ways.



Acknowledgments

The State Water Plan staff thanks the following people for their guidance and support in the preparation of this State Water Plan report: Stephen M. Mahfood, director of the Missouri Department of Natural Resources, Mimi Garstang, State Geologist and director of the department's Geological Survey and Resource Assessment Division (GSRAD); Mike Wells, deputy director, GSRAD; and Steve McIntosh, director, Water Resources Program within GSRAD.

The State Water Plan staff is grateful for the help of the department's Southwest Regional Office (SWRO), under the direction of Bruce Martin and Southeast Regional Office, under the direction of Gary Gaines, for initial identification of water use problems and opportunities in southwestern and southeastern Missouri. We extend a special thanks to Cindy Davies, SWRO deputy director for her assistance.

In addition, the staff acknowledges the contributions made by the State Water Plan, Inter-Agency Task Force (IATF) members. The IATF representatives were: Al Buchanan, representing the Missouri Department of Conservation

(a special thanks for the many written comments), Steven Krysiak, representing the Missouri Department of Health and Senior Services, David Silvester, representing the Missouri Department of Transportation; Don Yoest, representing the Missouri Department of Agriculture. Missouri Department of Economic Development, Missouri Department of Public Safety, and University of Missouri are member agencies of the IATF but were not able to attend.

The State Water Plan staff especially express their appreciation to Susan Dunn (graphic artist - GSRAD) for preparing illustrations and layout of this report. Denise Becker (editor - GSRAD) provided final editing and Steve McIntosh, director of GSRAD's Water Resources Program served as project manager. Special thanks to Dr. Mubarak Hamed, water resources economist and the State Water Plan staff without whose work this would not be possible - Richard M. Gaffney, Charles Hays, Terry Frueh, and Bruce Netzler, who as the State Water Plan staff director, was an important contributor and oversaw editing changes and final organization of this report.

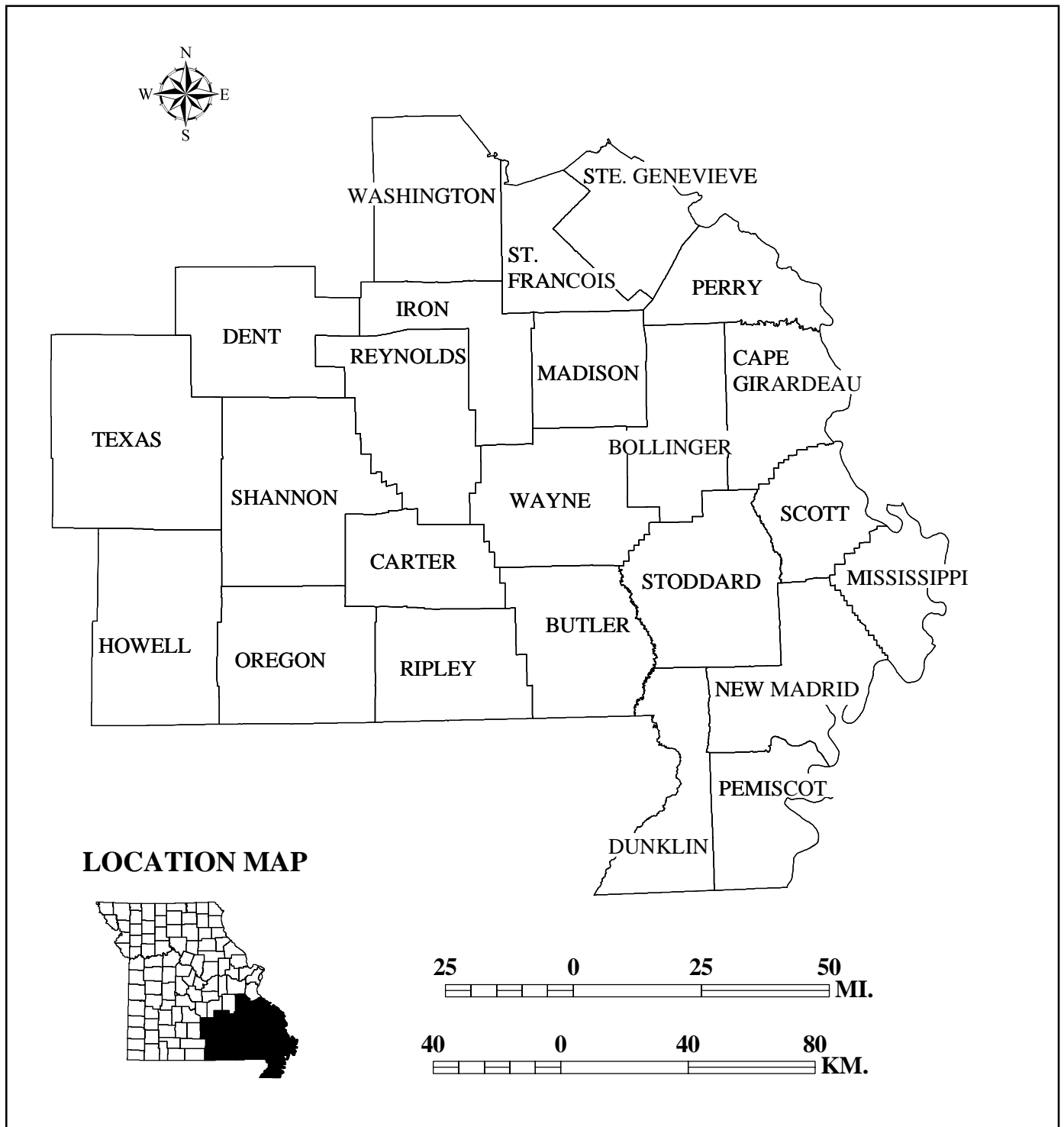


Figure 2. Map showing counties of southeast Missouri region covered by this report.



Regional Description

The scope of this report covers the entire southern region of Missouri, which includes 46 counties (figure 1). Due to this large number of counties this regional description section has been divided into two separate sub-sections, the southeastern region and the southwestern region.

Southeastern Missouri Regional Description

The southeastern region covers 24 counties in Missouri. These counties are Bollinger, Butler, Cape Girardeau, Carter, Dent, Dunklin, Howell, Iron, Madison, Mississippi, New Madrid, Oregon, Pemiscot, Perry, Reynolds, Ripley, St. Francois, Ste. Genevieve, Scott, Shannon, Stoddard, Texas, Washington, and Wayne (figure 2).

The State of Arkansas forms the southern boundary of the region (except where the St. Francis River separates the states), and the Mississippi River forms the eastern boundary. Seven of the 24 counties in the southeastern region front on the Mississippi River, a path of commerce since aboriginal times.

Colleges and Universities

There are four primary colleges situated in the counties of the southeastern region. The list includes, alphabetically, Mineral Area College, Park Hills (St. Francois Co.); Southeast Missouri State University, Cape Girardeau (Cape Girardeau Co.); Southwest Missouri State University-West Plains (Howell Co.) and Three Riv-

ers Community College, Poplar Bluff (Butler Co.) (figure 3). There also are branches of other colleges that offer courses in the region.

Regional Transportation

Navigation

River transportation in the southeastern region of Missouri is entirely by way of the Mississippi River, other than the numerous streams used for recreational purposes. The Mississippi River handles large amounts of out-bound grain destined for export. The inland waterway system of southeastern Missouri is a valuable resource that reduces the costs of transportation, encourages agricultural and industrial development, and establishes a direct link to regional, domestic, and world trade for Missouri products. The growth rate of waterborne commerce in southeastern Missouri is growing at approximately the same pace as the National Gross Domestic Product (Black & Veatch, 2000).

Pemiscot County Port is an intermodal interchange facility, slack-water harbor, and ranks among the top facilities in the state in shipping tonnage. It is a year-round, ice-free facility. Southeast Missouri Port is also a slack-water harbor that handles general cargo, dry bulk commodities and liquid fertilizer. It has a fleet area that can hold up to 100 barges. The Mississippi County Port handles dry bulk materials and is operational during periods of high water. New Madrid Port facility is an ice-free harbor that is accessible by rail and truck. The New Bourbon Regional Port is under construction. When completed, it will be a slack-water harbor and pub-

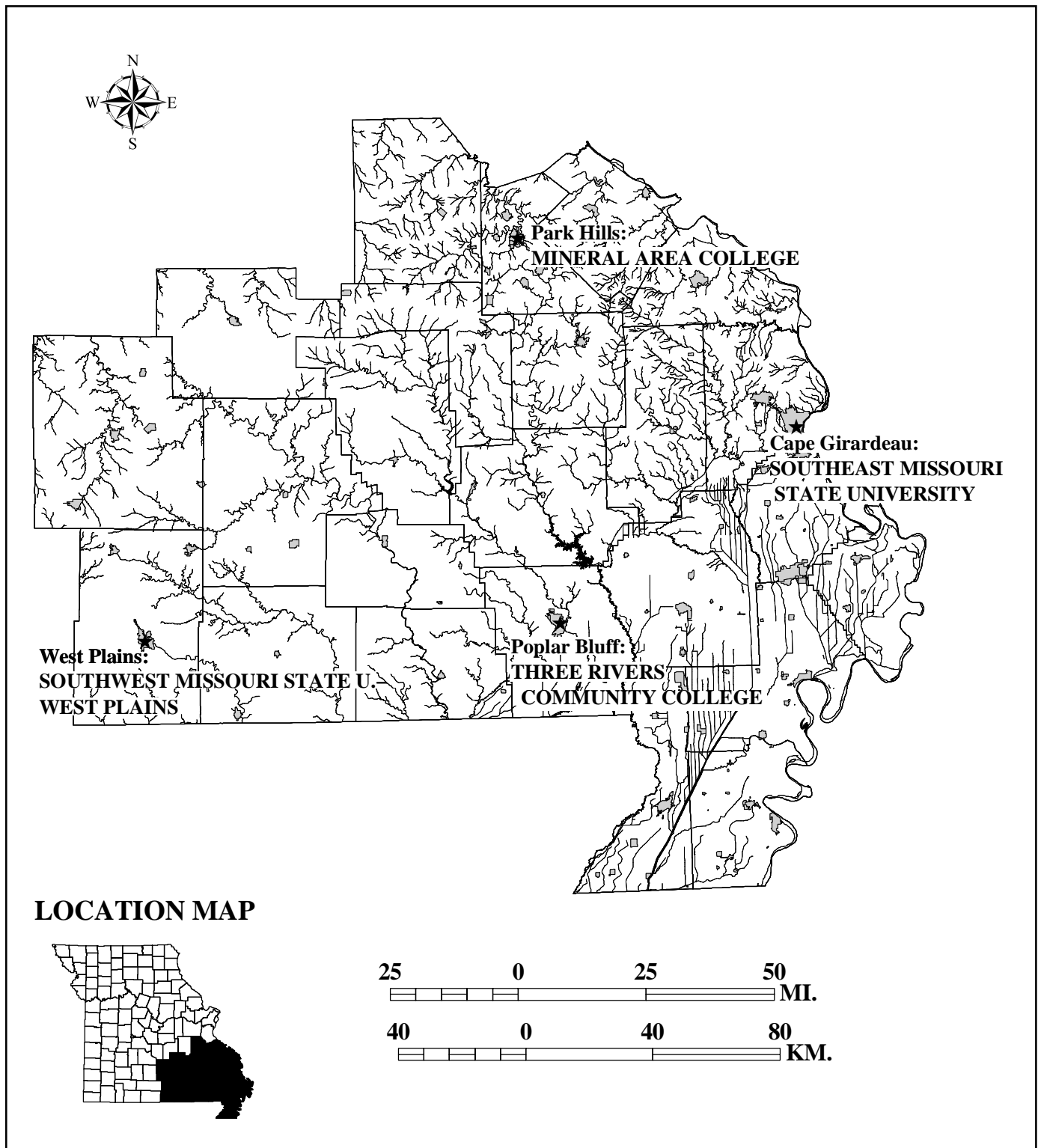


Figure 3. Locations of colleges and universities in southeast Missouri.

lic transfer facility that can accommodate inbound and outbound products by rail or truck (MoDOT, 2002). Numerous private facilities can be found along the river (figure 4).

Two ferries cross the Mississippi River, one is at Ste. Genevieve crossing to Modoc, Illinois and one is at Dorena, crossing to Hickman, Kentucky. One ferry is located on the Current River in Shannon County at Akers (MoDOT, 2002).

Railroads

Passenger rail transportation via Amtrak has one trunk line across the southeastern Missouri region, stopping in Poplar Bluff, running between St. Louis and Little Rock, Arkansas. There are two Class 1 rail freight service companies in the southeastern region of Missouri: Burlington Northern-Santa Fe (BNSF) and Union Pacific (UP) (figure 4).

Aviation

Cape Girardeau Regional Airport is the only one with commercial airline service. There are numerous other small airports serving the region.

Highways

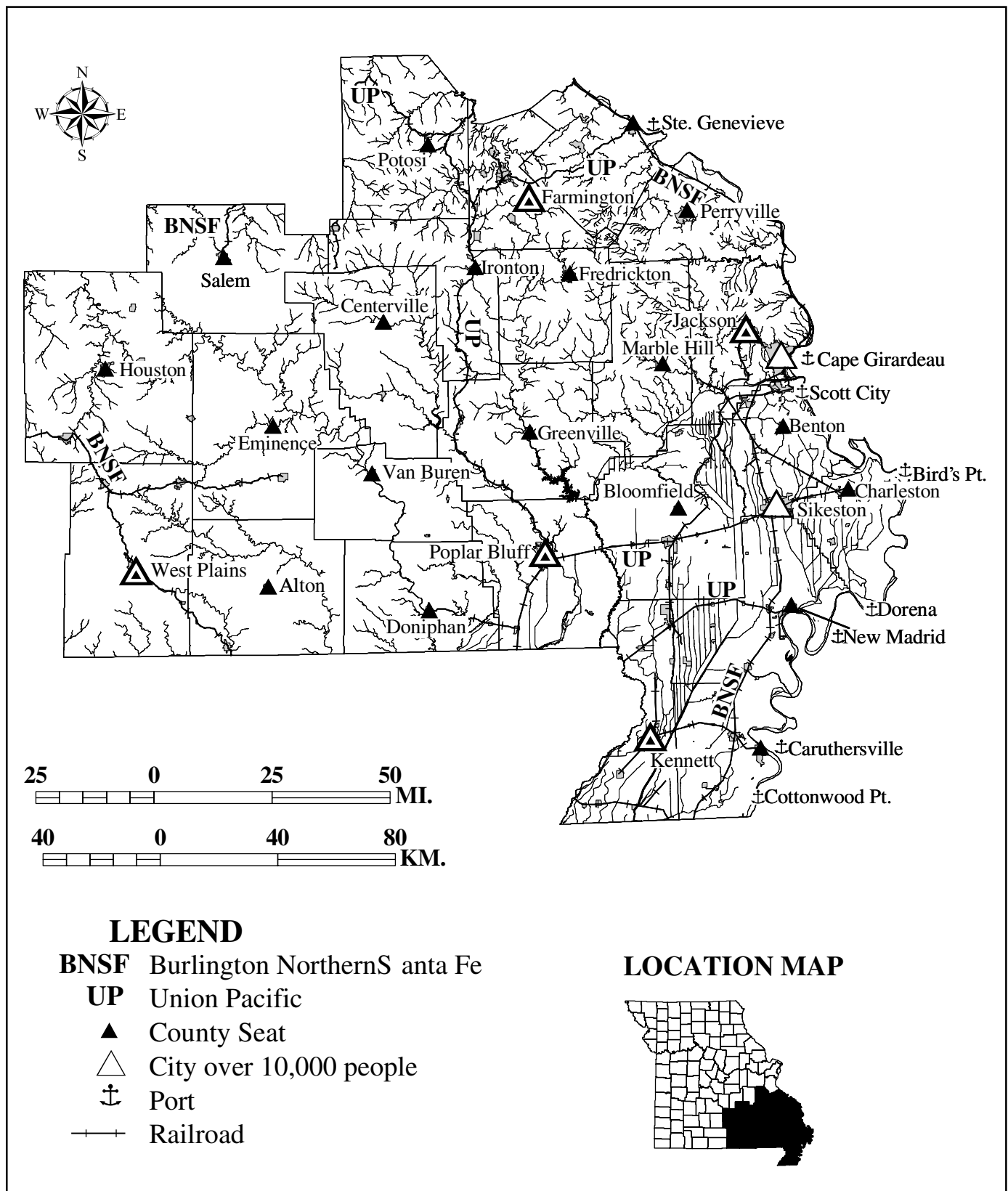
U.S. Interstate Highway transportation routes include I-55, which roughly parallels the Mississippi River, and a small portion of I-57, which crosses the Mississippi River near Cairo, Illinois and ends at Sikeston; I-155 crosses the Mississippi River south of Caruthersville, going into Tennessee.

Other major U.S. numbered highways include Route 61, north-south through the southeastern Missouri region, paralleling and sometimes coinciding with I-55; Route 63, running north-south, which connects West Plains with Rolla and Columbia; Route 67, north-south and connecting Poplar Bluff with St. Louis; Route 60, east-west, connecting Sikeston, Poplar Bluff, and Springfield; and Route 160, east-west, connecting Poplar Bluff, West Plains, and the Branson area (figure 5).

Population Characteristics

Some of the southeastern Missouri counties grew in population during the 1990s, and some lost. In contrast to the large population growth in southwestern Missouri, three Bootheel counties (Mississippi, New Madrid, and Pemiscot) were in the top 5 counties in the state in losing people. Howell was the only county in the region to grow by more than 15 percent in population during the decade. The entire region's population grew by 7 percent (35,000) during the past decade, which is less than the statewide average of 9.3 percent.

The largest city in the region is Cape Girardeau, at 35,349 people; Sikeston follows at 16,992. Total population for the region, according to the 2000 census, was 548,795 (table 1). This represents an average of 34.6 persons per square mile. 51.3 percent of the population in the 24-county region is female, with 48.7 percent male. Sixty-three percent of the total population were rural residents in 1990. By age groups, 25.3 percent of the population is less than 18 years old, 8.9 percent is 18-24, 26.8 percent is 25-44, 23.4 percent is 45-64, and 15.6 percent is 65 or older. The median age is 37 years, 7 months. The 2000 census identified 246,121 housing units and 215,804 households within the region (Census Bureau, 2002).



County Name.	County Seat	Major Town(s)	River Port(s)
Bollinger-12,029	Marble Hill-1,502		
Butler-40,867	Poplar Bluff-16,651		
Cape Girardeau-68,693	Jackson-11,947	Cape Girardeau-35,349	Cape Girardeau-35,349
Carter-5,941	Van Buren-845		
Dent-14,927	Salem-4,854		
Dunklin-33,155	Kennett-11,260	Campbell-1,883	
		Clarkton-1,330	
		Malden-4,782	
		Senath-1,650	
Howell-37,238	West Plains-10,866	Mountain View-2,430	
		Willow Springs-2,147	
Iron-10,697	Ironton-1,471		
Madison-11,800	Fredrickton-3,928		
Mississippi-13,427	Charleston-4,732	East Prairie-3,227	*Bird's Point
			*Dorena
New Madrid-19,760	New Madrid-3,334	Gideon-1,113	New Madrid-3,334
		Lilbourn-1,307	
		Morehouse-1,015	
Oregon-10,344	Alton-668	Portageville-3,295	
Pemiscot-20,047	Caruthersville-6,760	Thayer-2,201	
		Hayti-3,207	Caruthersville-6,760
		Steele-2,263	*Cottonwood Pt.
Perry-18,132	Perryville-7,667		Perryville-7,667
Reynolds-6,689	Centerville-171		
Ripley-13,509	Doniphan-1,932		
St. Francois-55,641	Farmington-13,924	Bonne Terre-4,039	
		Desloge-4,802	
		Leadwood-1,160	
		Park Hills-7,861	
Ste. Genevieve-17,842	Sainte Genevieve-4,476		Sainte Genevieve-
4,476			
Scott-40,422	Benton-732	Chaffee-3,044	Scott City-4,591
		Miner-1,056	
		Oran-1,264	
		Scott City-4,591	
		Sikeston-16,992	
Shannon-8,324	Eminence-548	Winona-1,290	
Stoddard-29,705	Bloomfield-1,952	Advance-1,233	
		Bernie-1,777	
		Dexter-7,356	
Texas-23,003	Houston-1,992	Cabool-2,168	
		Licking-1,471	
Washington-23,344	Potosi-2,662		
Wayne-13,259	Greenville-451	Piedmont-1,992	

Source: Census Bureau Website: www.census.gov, June 2001.

(* indicates place is unincorporated, and therefore does not have census data)

Table 1. Southeast Missouri region counties and their population.

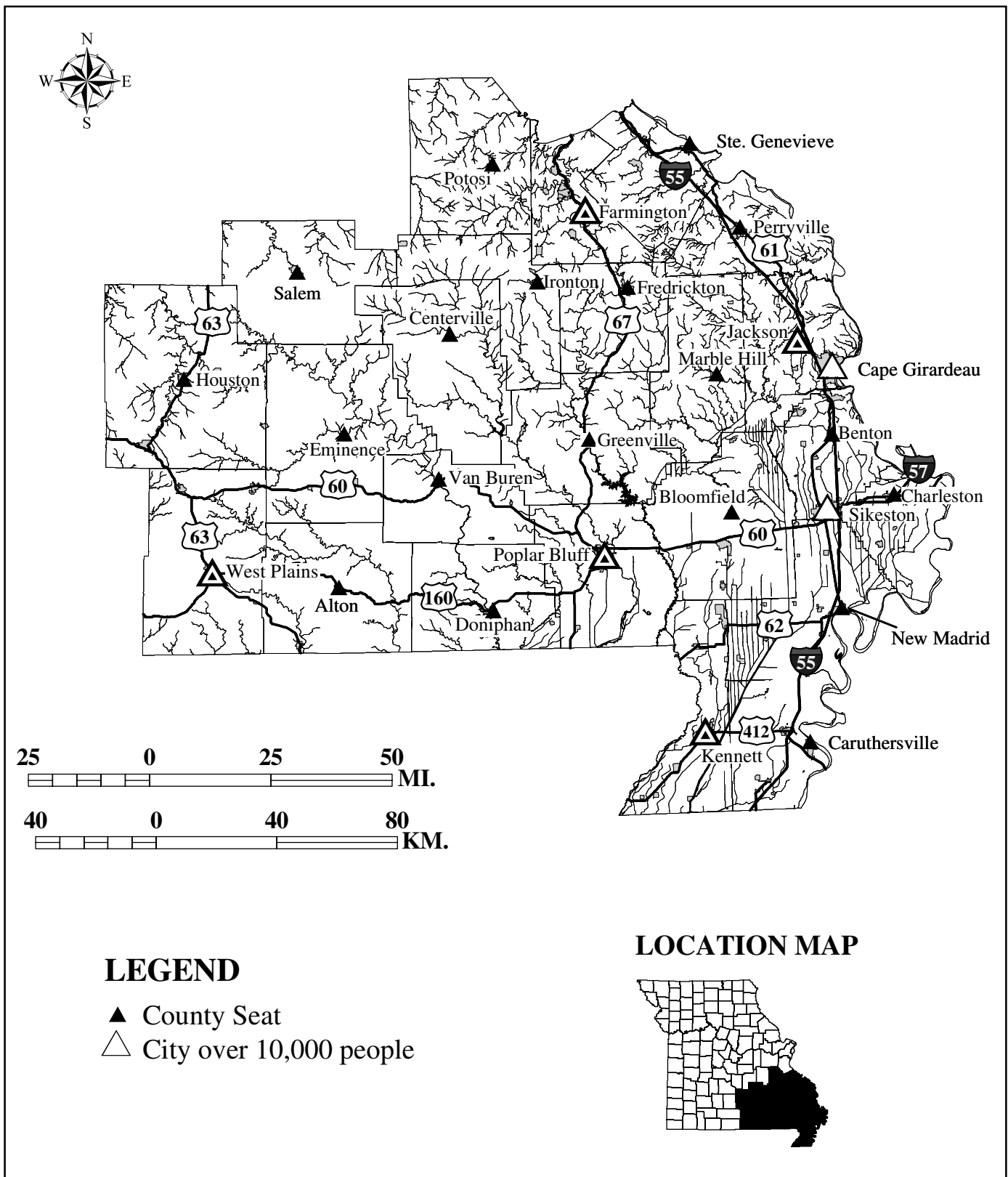


Figure 5. Major roads and cities in southeast Missouri.

Education statistics list 16 percent of the region's residents 25 and older with less than a 9th grade education, 20.5 percent had greater than 9th grade but less than 12th, 45.3 percent had graduated from high school, 13.5 percent were college degreed and 4.7 percent held graduate degrees. Employment and income data show 22.4 percent of the available workforce were managers/professionals, 21.6 percent held technical/ sales/ administrative positions, 15 percent were employed in a service industry, 1.7 percent farming and farm related, and 32.7 percent in "other" employment sectors. The average annual household income was \$28,582 and the average home value was \$63,552. The unemployment rate for the region was at 6.5 percent. Approximately 17.4 percent of the region's residents were at or below the poverty level (Census Bureau, 2002).

Industry, Commerce and Agriculture

Industry in the southeastern region is highly diversified. This helps keep the area's economy stable. In 2000, the manufacturing sector employed over 37,000 people, which accounted for 20 percent of the regional employment. Some of the large companies in the region include Briggs and Stratton, Gates Rubber Co., the Doe Run Resources Corp., Tyson Shared Services, Inc., Rowe Industries, Noranda Aluminum, Inc., and others.

Trade and services industries employ over 90,000 people, which accounted for 50 percent of the regional industry employment in 2000 (DED, 2000). In 2001, Cape Girardeau and New Madrid were among the seven counties that experienced the largest gains in retail consumers and sales from outside their borders in Missouri (DED, 2001).

Agriculture continues to be a solid base for the economy of Southeast Missouri. In 1997, 16 percent of Missouri farms were located in the southeast region (USDA, 1997). The Southeastern region specialized in rice and cotton production. Dunklin, New Madrid, Pemiscot, Scott, and Stoddard Counties accounted for 99 percent of the total cotton produced in Missouri

(Missouri Agricultural Statistical Services, 2001). Butler, Dunklin, New Madrid, Pemiscot, Ripley, and Stoddard Counties accounted for 98 percent of the total rice produced in Missouri (Missouri Agricultural Statistical Services, 2001). Texas County led the State in beef cows production in 1998-99. Howell County ranked second in cattle and calves production in Missouri during 1998-99. Mississippi, New Madrid, Pemiscot, and Stoddard were the leading counties for wheat and soybean production in the state during 1998-99.

Physical Characteristics

Climate

Southeastern Missouri has a humid, continental climate with average annual temperatures from about 55 degrees F to 58 degrees F. Long term annual precipitation averages from 37 to 47 inches throughout the region (figure 6). Rainfall amounts are generally highest in the spring and lowest in the fall and winter months. Evapotranspiration, the process of precipitation being returned to the air through direct evaporation or transpiration of plants, consumes from 28 to 31 inches of annual rainfall. Surface runoff of precipitation averages from 12 to 20 inches annually.

Physiography

Southeastern Missouri lies mostly in the Salem Plateau of the Ozarks, with the St. Francois Mountains and Southeastern Lowlands comprising the rest of the region (figure 7). The Salem Plateau is composed of mostly Ordovician and Cambrian-age sedimentary rocks. The landscape is maturely dissected with steep-sided valleys separated by more gently rolling uplands. Modern soils are typically thin except for the upland areas. In those areas, bedrock is overlain by thick deposits of unconsolidated residuum (weathered rock), typically permeable, allowing high rates of groundwater recharge. Karst topography here is typical and widespread, and on a larger scale than in the Springfield Plateau

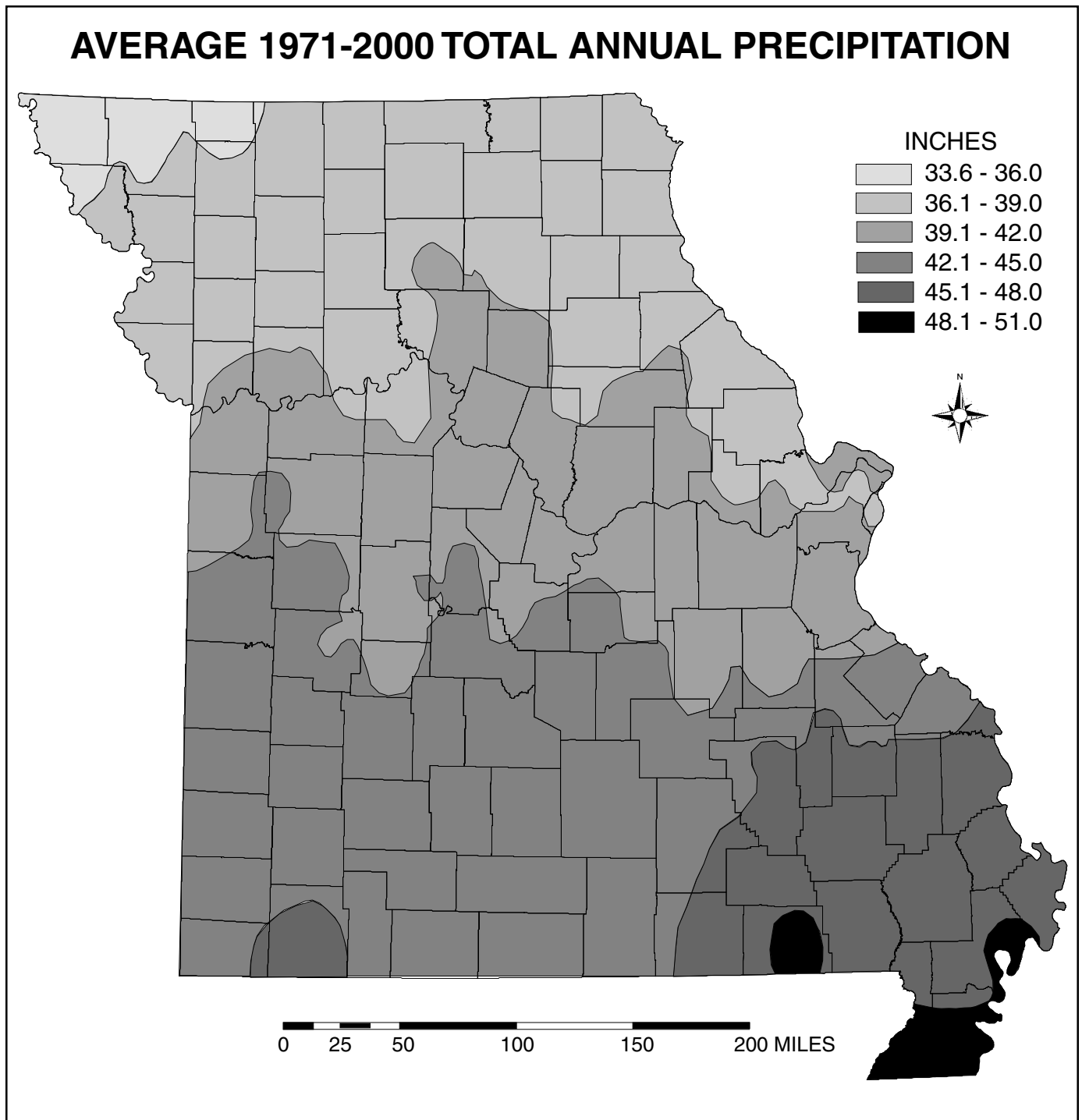


Figure 6. Missouri average annual precipitation from 1971 – 2000. Source: Office of State Climatologist, University of Missouri-Columbia.

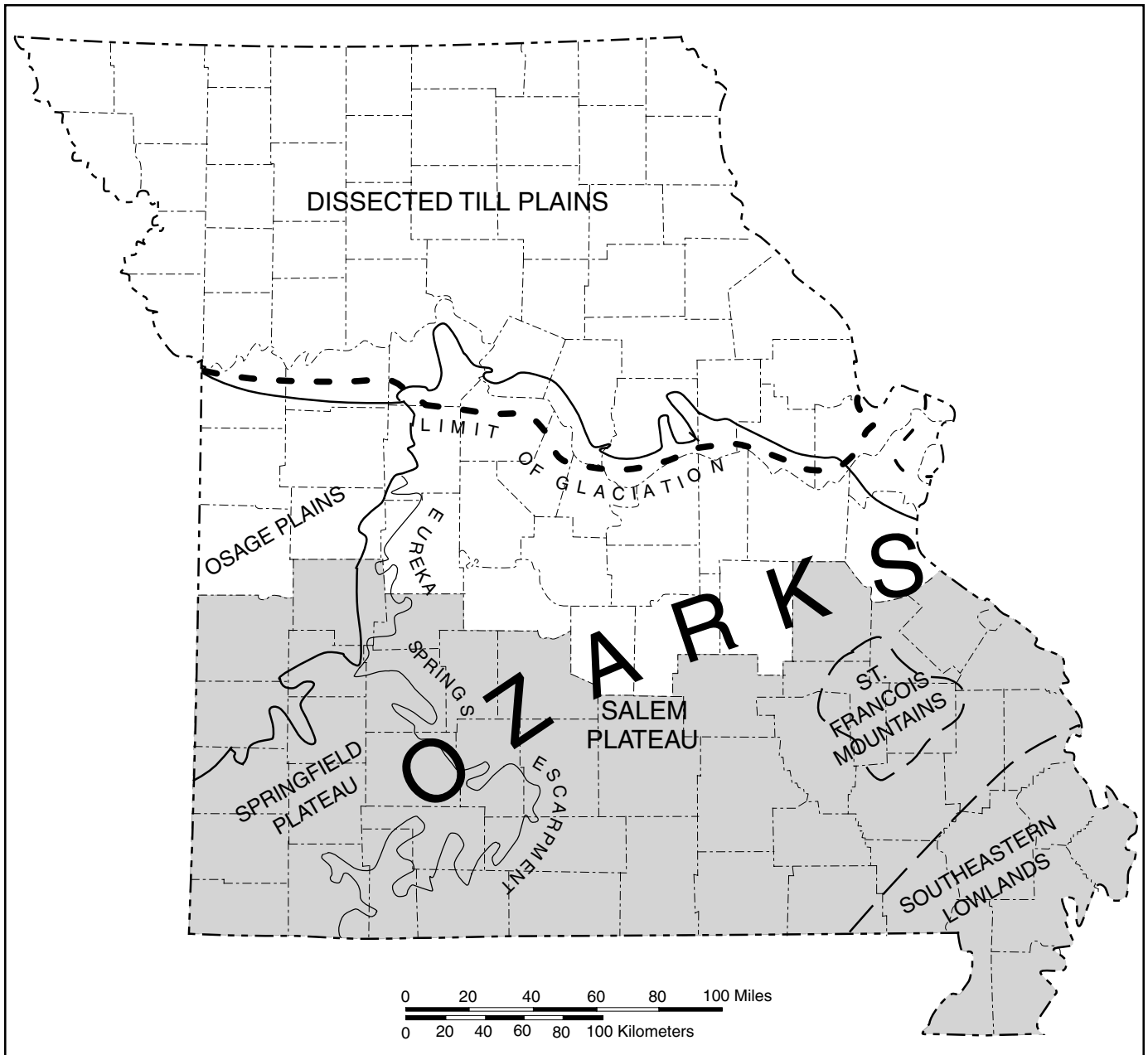


Figure 7. Physiographic provinces of Missouri. Source: Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division.

area. Water-supply wells in this area can yield large quantities of good-quality water. The aquifer in this area is known as the Ozark Aquifer, and is unconfined. It receives recharge primarily from precipitation and lateral movement of groundwater from outcropping bedrock.

The St. Francois Mountains are the highest points in Missouri, with the oldest rock outcroppings, a Precambrian igneous rock. The hills are steep, with thin soils. The igneous rock makes for a poor aquifer, and wells supply small quantities of water, although of good quality.

Water stored in the flood plain deposits of the Mississippi River and others is called alluvial groundwater. These deposits generally are very good sources of drinking water and alluvial wells generally yield large quantities of water. For example, the city of Ste. Genevieve gets its water from the alluvium.

Recreation

The hills, rivers and lakes in southeastern Missouri provide a scenic backdrop for 21 state parks and historic sites, and numerous conservation and wildlife areas (table 2). All types of water recreation, including fishing, sailing, swimming, canoeing, water-skiing, and motor boating are available on the area's reservoirs (primarily Clearwater Lake and Lake Wappapello). The area's pristine streams draw visitors from around the nation. These include the Current, Black, Eleven Point, Jacks Fork, and St. Francois Rivers.

<u>County</u>	<u>State Parks</u> ¹	<u>MDC</u> ²	<u>Federal</u> ³
Bollinger	0	13	2
Butler	0	17	2
Cape Girardeau	2	9	0
Carter	0	5	2
Dent	1	11	2
Dunklin	1	8	0
Howell	0	9	1
Iron	3	7	2
Madison	0	6	1
Mississippi	2	9	0
New Madrid	1	5	0
Oregon	1	6	1
Pemiscot	0	7	0
Perry	0	6	0
Reynolds	1	8	2
Ripley	0	11	1
Ste. Genevieve	2	10	1
St. Francois	3	5	1
Scott	0	3	0
Shannon	0	9	2
Stoddard	0	7	1
Texas	0	20	2
Washington	2	7	1
Wayne	2	13	3

Sources: ¹www.dnr.mo.gov/dsp/index.html; ²www.conservation.state.mo.us; ³www.fws.gov; ⁴www.usace.army.mil; ⁵www.nps.gov; ⁶www.af.mil; ⁷www.fs.fed.us

Table 2. Number of state and federal recreational facilities in southeast Missouri.

Sources:

Black and Veatch, July 19, 2000, **Public river ports of Missouri strategic plan and port capital improvement program: project summary**, prepared for Missouri Department of Transportation.

Missouri Agricultural Statistical Services, 2001, **2001 Missouri farm facts**, Missouri Department of Agriculture.

Missouri Department of Economic Development (DED), 2000, Missouri Economic Research and Information Center, **Missouri regional data**, available online at www.ded.missouri.gov/business/researchandplanning/regional/Bootheel/index.shtml

Missouri Department of Economic Development (DED), 2001, Missouri Economic Research and Information Center, **Missouri retail trade 2001**, available online at www.ded.state.mo.us/business/researchandplanning/industry/retail/retail.shtml

Missouri Department of Transportation, 2002, www.modot.state.mo.us/othertransportation/index.htm

Missouri Department of Transportation, 2002, <http://www.modot.state.mo.us/othertransportation/waterwaysmissouriwaterwaysmap.htm>

Missouri Department of Transportation, 2002, **Missouri fast facts: water resources programs for Missouri**.

Missouri Department of Transportation, 2002, **Domestic waterway commerce**, from National Waterways Conference.

Missouri Port Authority Association, 2002, www.missouriports.com

United States Department of Agriculture (USDA), 1997, National Agricultural Statis-

tical Services, **Census of agriculture**, available online at www.nass.usda.gov/census

United States Department of Commerce, September, 2002, United States Census Bureau Website: www.census.gov

Southwestern Missouri Regional Description

The southwestern regional covers 22 counties in Missouri. These counties are Barry, Barton, Cedar, Christian, Dade, Dallas, Douglas, Greene, Hickory, Jasper, Laclede, Lawrence, McDonald, Newton, Ozark, Polk, St. Claire, Stone, Taney, Vernon, Webster, and Wright (figure 8). There are parts of 7 major reservoirs located in the region. This is the only region of the state that does not border on a major river (either the Missouri or the Mississippi).

Colleges and Universities

Fourteen colleges and universities are situated in the counties of the southwestern region. The list includes, alphabetically, Baptist Bible College, Springfield (Greene Co.); Central Bible College, Springfield (Greene Co.); Cottey College, Nevada (Vernon Co.); Crowder College, Neosho (Newton Co.); College of the Ozarks, Point Lookout, (Taney Co.); Drury University, Springfield (Greene Co.); Evangel University, Springfield (Greene Co.); Forest Institute of Professional Psychology, Springfield (Greene Co.); Global University, Springfield (Greene Co.); Missouri Southern State College, Joplin (Jasper Co.); Ozark Christian College, Joplin (Jasper Co.); Ozarks Technical Community College, Springfield (Greene Co.); Southwest Baptist University, Bolivar (Polk Co.); Southwest Missouri State University, Springfield (Greene Co.) (figure 9). There also are branches of other colleges that offer courses in the region.

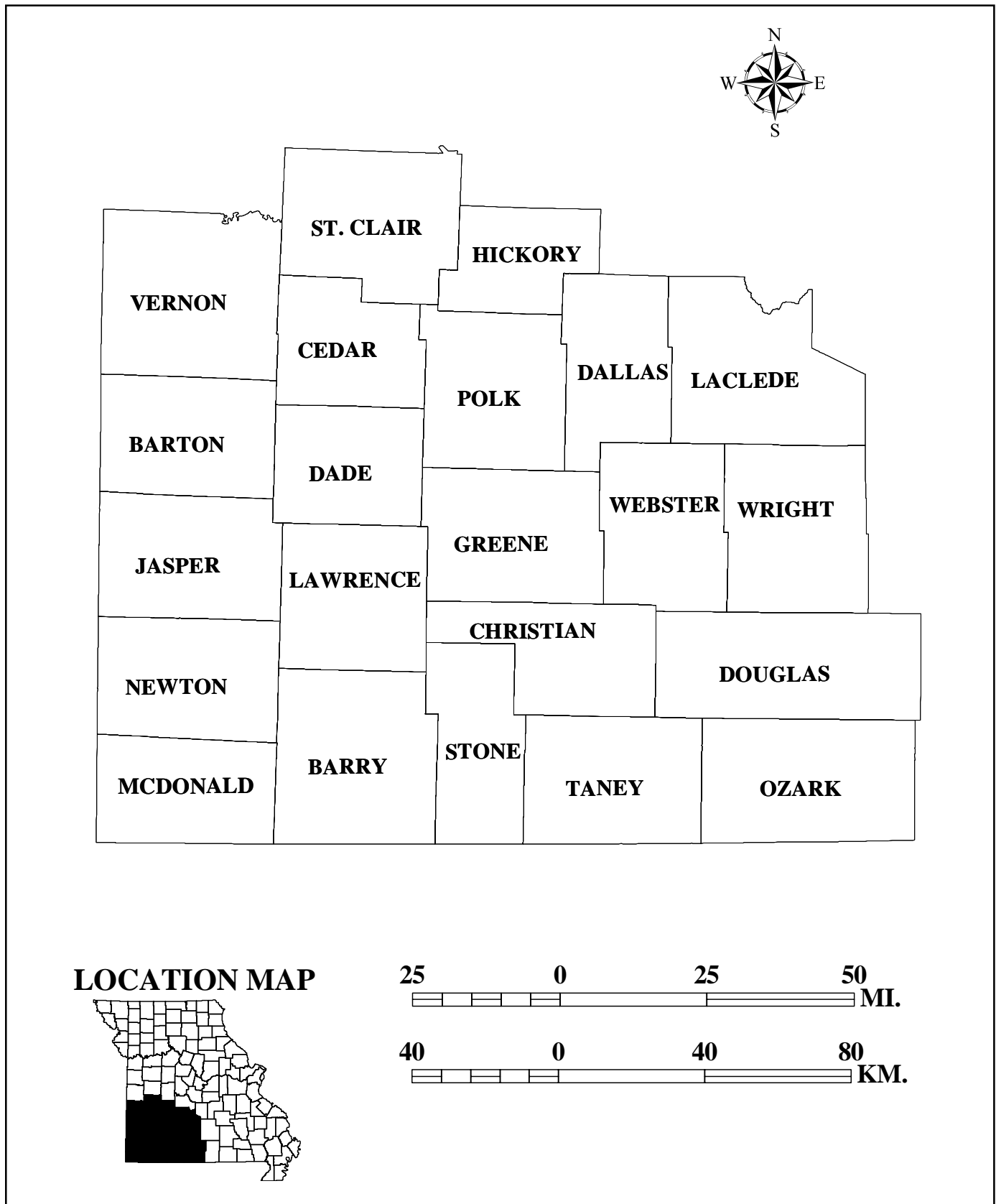


Figure 8. Map showing counties of southwest Missouri region covered by this report.

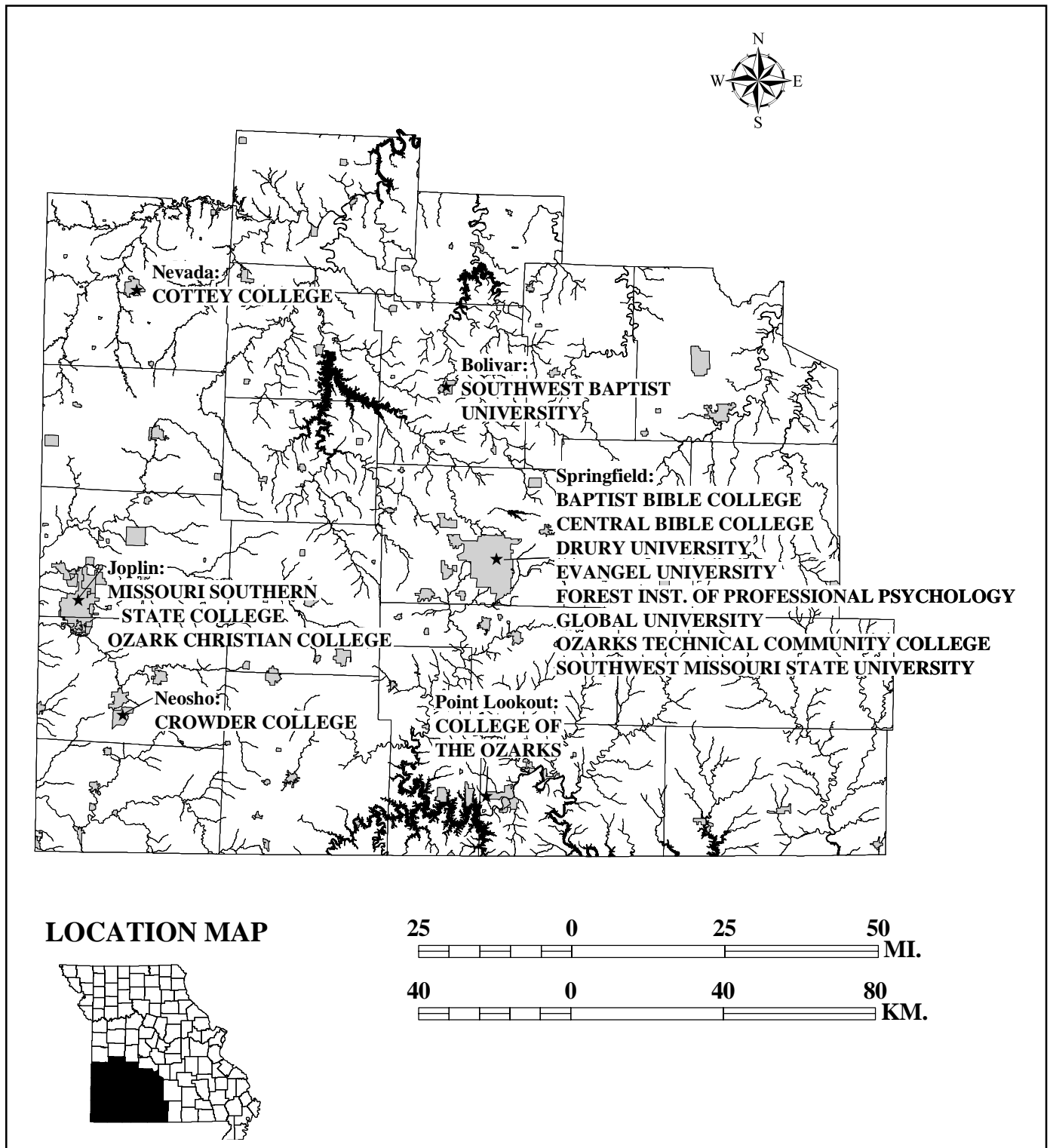


Figure 9. Locations of colleges and universities in southwest Missouri.

Regional Transportation

Navigation

There is no river transportation in the southwest region of Missouri, other than the numerous streams and rivers used for recreational purposes.

Railroads

There is no passenger rail service in the southwestern region of Missouri. However, there are several rail freight service lines in the region. Among the Class 1 railroads operating here are the Burlington Northern-Santa Fe (BNSF), and the Kansas City Southern Railway (KCS). The only Class 2 railroad is the regional Missouri & Northern Arkansas Railroad (MNA). There are two Class 3 railroads, the Arkansas and Missouri Railroad (AM), and the Southeast Kansas Railroad Company (SEKR) (figure 10).

Aviation

There are two commercial airports in the region, Springfield (the largest) and Joplin. In addition, numerous small or private airfields are located across the 22-county area.

Highways

The only U.S. Interstate in the region is I-44, which trends from northeast to southwest. It connects Springfield with St. Louis to the northeast, and Tulsa to the southwest. Other major U.S. numbered highways include Routes 71 and 65, north-south through the southwestern Missouri region; 54, 60, and 160 running east-west (figure 11).

Population Characteristics

All of the southwestern Missouri region grew in population during the 1990s. Christian, Taney and Stone Counties grew by over 50 percent during the decade, with Barry, Dallas, Hickory, Laclede, McDonald, Polk, and Webster Counties growing by 20-30 percent. The entire region's population grew by 25 percent (150,000) during the past decade.

The largest city in the region is Springfield, with over 150,000 people; Joplin follows at 40,000. Total population for the region, according to the 2000 census, was 831,289 (table 3). This represents an average of 60.3 persons per square mile with 50.1 percent of the population in the 22-county region being female and 49.9 percent were male. Fifty three percent of the total population was rural residents in 1990. By age groups, 24.9 percent of the population is less than 18 years old, 10.2 percent is 18-24, 27.4 percent is 25-44, 22.9 percent is 45-64, and 14.6 percent is 65 or older. The median age is 36 years, 8 months. The 2000 census identified 369,481 housing units and 328,606 households within the region (Census Bureau, 2001).

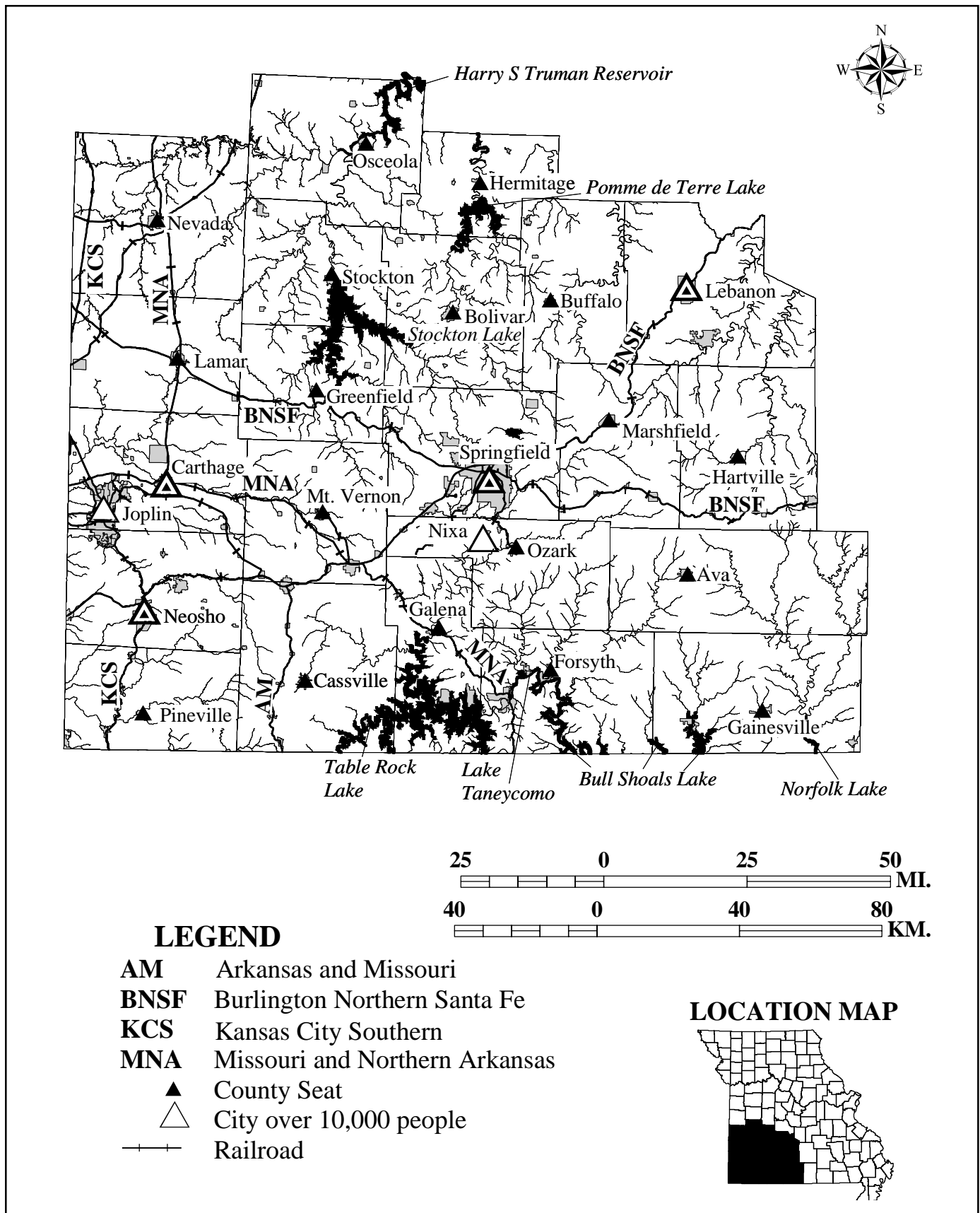


Figure 10. Railways in southwest Missouri.

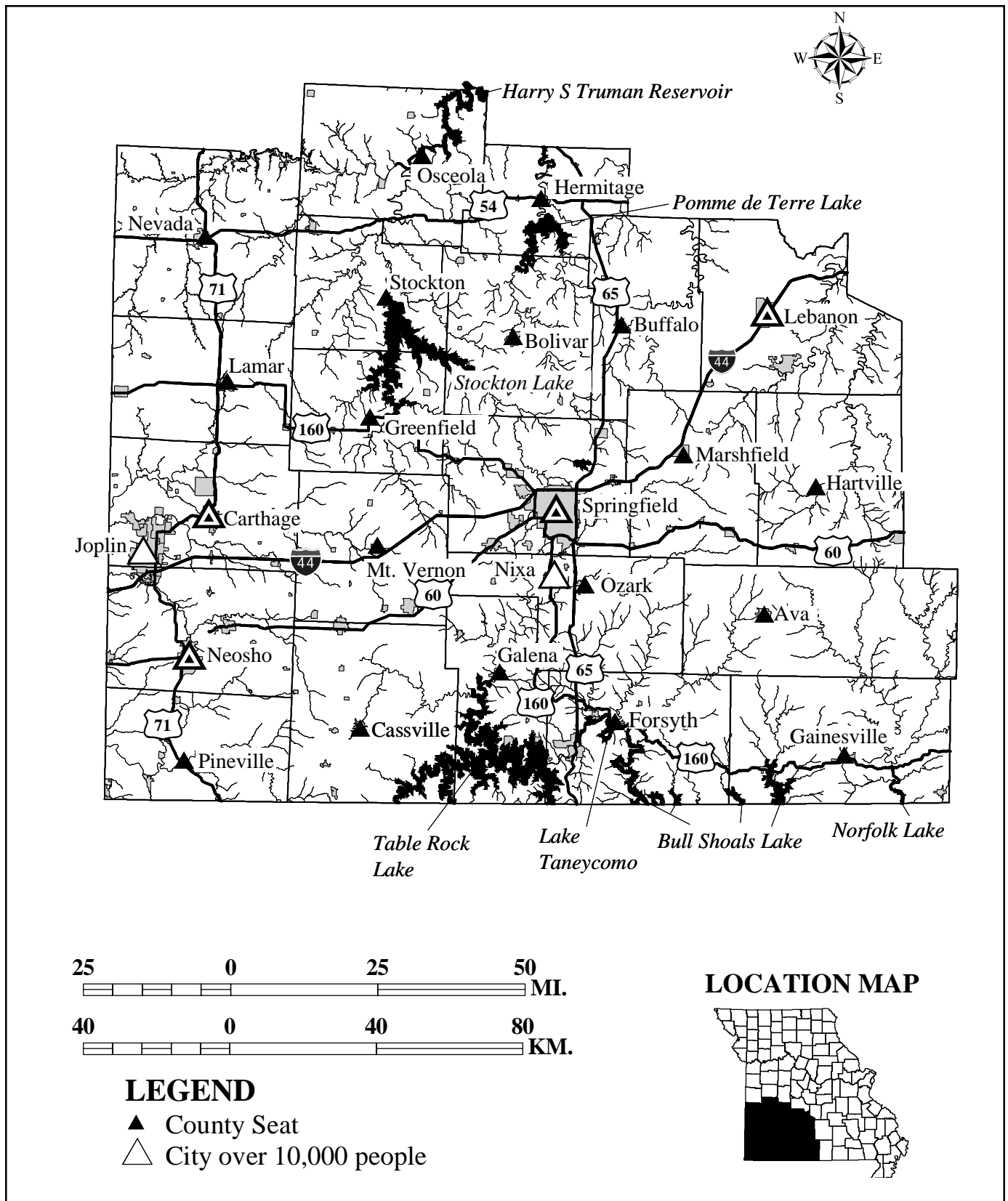


Figure 11. Major roads and cities in southwest Missouri.

<u>County Name.</u>	<u>County Seat</u>	<u>Major Town(s)</u>
Barry-34,010	Cassville-2,890	Monett-7,396
Barton-12,541	Lamar-4,425	
Cedar-13,733	Stockton-1,960	El Dorado Springs-3,775
Christian-54,285	Ozark-9,665	Nixa-12,124
Dade-7,923	Greenfield-1,358	
Dallas-15,661	Buffalo-2,781	
Douglas-13,084	Ava-3,021	
Greene-240,391	Springfield-151,580	Ash Grove-1,430
		Battlefield-2,385
		Fairgrove-1,107
		Republic-8,438
		Strafford-1,845
		Willard-3,193
Hickory-8,940	Hermitage-406	
Jasper-104,686	Carthage-12,668	Carl Junction-5,294
		Cartersville-1,850
		Joplin-40,433
		Webb City-9,812
Laclede-32,513	Lebanon-12,155	
Lawrence-35,204	Mt. Vernon-4,017	Aurora-7,014
		Marionville-2,113
		Pierce City-1,385
McDonald-21,681	Pineville-768	Anderson-1,856
		Goodman-1,183
		Noel-1,480
		Seneca-2,135
Newton-52,636	Neosho-10,505	
Ozark-9,542	Gainesville-632	
Polk-26,992	Bolivar-9,143	
St. Clair-9,652	Osceola-835	
Stone-28,658	Galena-451	Crane-1,390
		Kimberling City-2,253
Taney-39,703	Forsyth-1,686	Branson-6,050
		Hollister-3,867
Vernon-20,454	Nevada-8,607	
Webster-31,045	Marshfield-5,720	
Wright-17,955	Hartville-607	

Source: Census Bureau Website: www.census.gov, June 2001.

Table 3. Southwest Missouri region counties and their population.

Industry, Commerce and Agriculture

Industry in the southwestern region is varied. The manufacturing sector accounts for percent of the regional employment. In 2001, there were 67,000 people employed in manufacturing. Some of the well-known companies in the region include: Butterball Turkey, EFCO Corp., La-Z-Boy Chair Co., Minnesota Mining and Manufacturing Co., Bass Pro Shops, Fasco Industries, General Electric, Jack Henry, Kraft Foods, MCI, Tracker Marine, Tyson Foods, and many others.

Trade and services industries accounted for 50 percent of the regional industry employment in 2000 (DED, 2000). In 2001, Branson, Springfield, and Joplin were among the areas that experienced the largest gains in retail consumers/sales from outside their borders in Missouri, due to the presence of tourism/recreation amenities in the region (DED, 2001). The annual retail sales in the region have been over \$8 billion and well over \$5 billion for the Springfield metro area (Springfield Chamber of Commerce, 2002).

Agriculture continues as a solid base for the economy of southwestern Missouri. In 1997, 26 percent of Missouri farms were located in the southwestern region (USDA, 1997). Seven of the counties in the southwestern region were included in the 1998-99 top ten list for hay production in Missouri. Barton County was a leading county in Sorghum production in Missouri in 1998-99. Vernon County led the state in hogs and pigs production in 1998-99. Eight of the counties in the southwestern region were ranked in the 1998-99 top ten list for the estimated number of milk cows. Broilers and turkeys are dominant in the southwestern counties. The poultry industries in the southwestern counties produce nearly enough chicken and enough turkey to meet the needs of Missouri consumers plus some counties in surrounding states (Young *et al.*, 2001).

Physical Characteristics

Southwestern Missouri has a humid, continental climate with average annual temperatures from about 55 degrees F to 58 degrees F. Long term annual precipitation averages from 39 to 42 inches throughout the region (figure 6). Rainfall amounts are generally highest in the spring and lowest in the fall and winter months. Evapotranspiration, the process of precipitation being returned to the air through direct evaporation or transpiration of plants, consumes from 28 to 30 inches of annual rainfall. Surface runoff of precipitation averages from 9 to 15 inches annually.

Southwestern Missouri contains parts of three distinct physiographic regions: the Salem plateau of the Ozarks, the Springfield plateau, and the Osage Plains (figure 7). The first two are similar in their hilly nature and thin, easily eroded soils. They both often have abundant groundwater, in addition to numerous areas of karst topography.

The Osage Plains are distinct from the other two regions. Most of Barton, St. Clair, and Vernon counties, and parts of Cedar, Dade, and Jasper Counties lie in the Osage Plains subprovince of the Central Lowlands physiographic province. These plains are unglaciated and have more gentle topography than the Ozarks. This is generally because more competent Pennsylvanian-age shale, limestone, and sandstone underlie the area. This part of the southwestern region coincides with the freshwater-saline water transition zone (figure 12). Therefore, the deeper Springfield Plateau aquifer and the Ozark Aquifer contain water too highly mineralized for use. Nearer the surface, Pennsylvanian-age rocks locally are capable of yielding small amounts of marginal-quality water. Most water districts in this area use surface water resources.

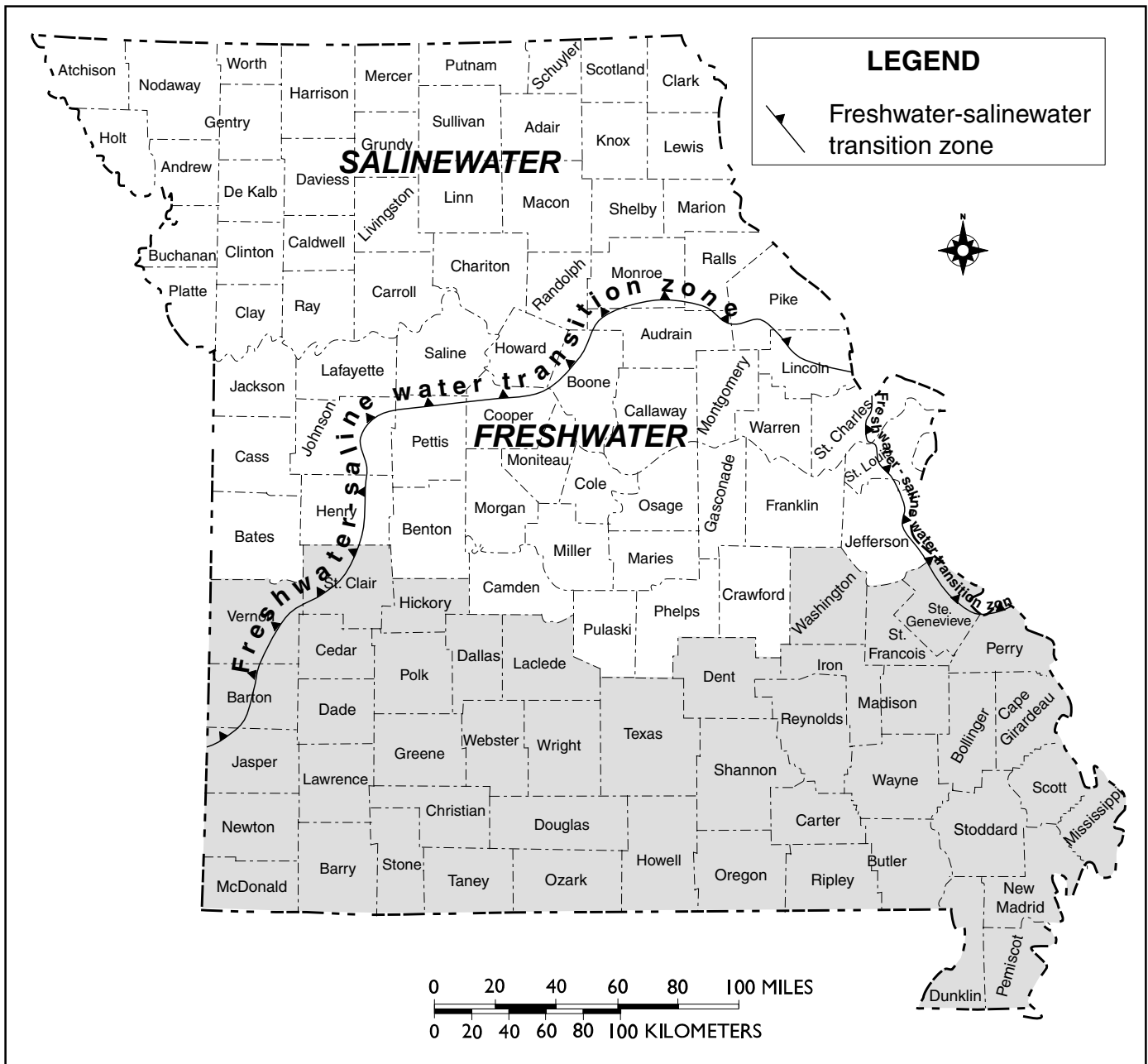


Figure 12. Freshwater-salinewater transition zone. Source: Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division.

Recreation

The hills, rivers and lakes in southwestern Missouri provide a scenic backdrop for eleven state parks and historic sites, and numerous conservation and wildlife areas (table 4). All types of water recreation, including fishing, sailing, swimming, canoeing, water-skiing, and motor boating are available on the area's reservoirs, of which there are parts of seven major reservoirs. Stockton Lake is highly regarded for sailing, because the hills surrounding the lake are low enough to allow good sailing winds to reach

the water surface. In other parts of the Ozarks region, the hills shield the water from breezes.

The Branson area of Missouri is very scenic. Table Rock Lake is noted for bass fishing, and below the lake, in the Upper White River (Lake Taneycomo), there is a cold-water trout fishery that is renowned. Besides water sports and historic sites, the Branson area also is home to a wealth of musical entertainment, primarily of the Southern Appalachian-Ozarkian style of country music. Large theaters, restaurants, and shopping attract an international array of visitors of all ages.

<u>County</u>	<u>State Parks¹</u>	<u>MDC²</u>	<u>Federal³</u>
Barry	1	7	2
Barton	2	16	0
Cedar	1	6	1
Christian	0	4	1
Dade	0	8	1
Dallas	1	11	0
Douglas	0	5	1
Greene	1	9	1
Hickory	1	6	2
Jasper	1	5	0
Laclede	1	13	1
Lawrence	0	7	1
McDonald	1	9	0
Newton	0	15	1
Ozark	0	10	2
Polk	0	7	2
St. Clair	0	9	1
Stone	0	8	2
Taney	1	6	2
Vernon	1	14	0
Webster	0	4	0
Wright	0	8	1

Sources: ¹www.dnr.state.mo.us/dsp/index.html; ²www.conservation.state.mo.us; ³www.fws.gov; ⁴www.usace.army.mil; ⁵www.nps.gov; ⁶www.af.mil; ⁷www.fs.fed.us

Table 4. Number of state and federal recreational facilities in southwest Missouri.

Sources:

- Missouri Department of Economic Development (DED), 2000, Missouri Economic Research and Information Center, **Missouri regional data**, available online at www.ded.state.mo.us/business/researchandplanning/regional/northwest/index.shtml
- Missouri Department of Economic Development (DED), 2001, Missouri Economic Research and Information Center, **Missouri retail trade 2001**, available online at www.ded.state.mo.us/business/researchandplanning/industry/retail/retail.shtml
- Springfield Area Chamber of Commerce, 2002, Springfield Business and Development Corporation, **Demographic and statistics**, available online at www.businessforspringfield.com
- United States Department of Agriculture (USDA), 1997, National Agricultural Statistical Services, **Census of agriculture**, available online at www.nass.usda.gov/census
- Young, R., *et al.*, 2001, **Positive approaches to phosphorus balancing in southwest Missouri**, report # 16-01 November 2001, Food and Agricultural Policy Research Institute - University of Missouri - Columbia.



Regional Water Use Overview

The scope of this report covers the entire southern region of Missouri, which includes 46 counties. Due to this large number of counties this regional water overview section has been divided into two separate sub-sections, the southeastern region and the southwestern region.

Southeastern Regional Water Use Overview

Water Resources Management

There are many issues that confront and hinder water resource managers. Watershed management has now become the preferred method for evaluating water resources and identifying problems and solutions. A watershed may be defined as the natural or disturbed unit of land on which all the water that falls (or emanates from springs or snowmelt), collects by gravity and fails to evaporate, and runs off via a common outlet (Gaffney and Hays, 2000). While these units are natural and logical boundaries, they seldom follow political boundaries. This creates a problem for planners who must now coordinate many agencies, municipalities, and varied interests. Cooperation among all stakeholders is usually needed to implement and manage an effective watershed management plan. This cooperation is often difficult, if not impossible. On the local level, municipalities may not have the funding, expertise, or political will to become involved in a regional or state plan.

On many water topics, there are organizational challenges to address. For example, the protection of wetlands involves many state and federal agencies. Some wetlands manipulation require federal permits while others do not, and this situation appears to change frequently in the wake of federal court decisions. There are federal and state guidance and executive orders, all of which back the concept of stopping the loss of wetlands. However, there are few formal means to prevent wetlands loss when many activities that destroy wetlands are beyond regulation. An understanding of the missions of each agency involved in the discussion, as well as what assistance each can lend, would be useful in solving the larger problem (Madras, 2001).

The state is working with the Corps of Engineers (COE) districts to unify the approaches to Section 404 permits and their corresponding Section 401 water quality certifications. Similarly, the state is working with parties that frequently obtain certifications so that the requirements of certifications can be accommodated within the design of the projects. A major initiative is to make these requirements known at an early stage of the process so the design can anticipate them (Madras, 2001).

Jurisdictional issues also arise in water resources planning and management. Most river basins are inter-state and therefore, fall under federal oversight. This is implicit in the United States Constitution, in which the federal government reserves the right to “regulate commerce with foreign nations, and among the several states, and with the Indian tribes.” In the early years of our country, commerce was carried out via waterways and navigation was an important issue. A stream is considered navigable if it can float a boat that can be involved

in commerce. It was also deemed that the defense of our country was dependent in large part on the protection of navigable waters.

The COE is now involved with granting permits for dredge and fill in navigable waters, flood control, water supply, dam safety, floodplain management, and more recently, environmental protection and restoration. The Environmental Protection Agency (EPA) is another agency involved in water resources. Created in 1970 by President Nixon, it is an arm of the executive branch and has risen to cabinet level. It is charged with administration of the "Clean Water Act (CWA)." It is involved in water resource planning, research, and enforcement. In most cases, the EPA has delegated much authority to the states in regards to water resources protection and management. Recent court rulings may have both clouded and clarified the role of the COE in determining what wetland areas are and are not within their administrative jurisdiction to regulate under the CWA and other federal laws.

Because Missouri has 1,320,900 acres of National Forest, a brief discussion of the U.S. Forest Service is warranted (figure 13). One of the earliest mandates of the national forest service was to protect water supplies as well as timber resources. Today, forestry and logging

activities take place on national forests, including those in Missouri. The forest service manages our forests under the concept of "multiple use" in which many activities such as recreation (hunting, fishing, biking, bird watching, etc), water protection, and logging are permitted. Recently, the Forest Service has begun to use an ecosystem management approach to guide forest policy. This also opened the policy-making process to public participation in which competing demands are often considered and evaluated. The way these forests are managed has important implications for water quality in our state.

The following description of water use in southwestern Missouri is included to provide context for the water use problems identified in this report. As part of the major Water Users Law (RSMo 256.400), the Department of Natural Resources', Water Resource Program compiles water use information. Major water users are defined as those users that are capable of pumping greater than 100,000 gallons of water per day from either groundwater or surface water. The Major Water Users Database includes information about location, amount of water used, and type of use (domestic, municipal, electrical generation, fish and wildlife, and drainage.) This data is submitted to the United States Geo-

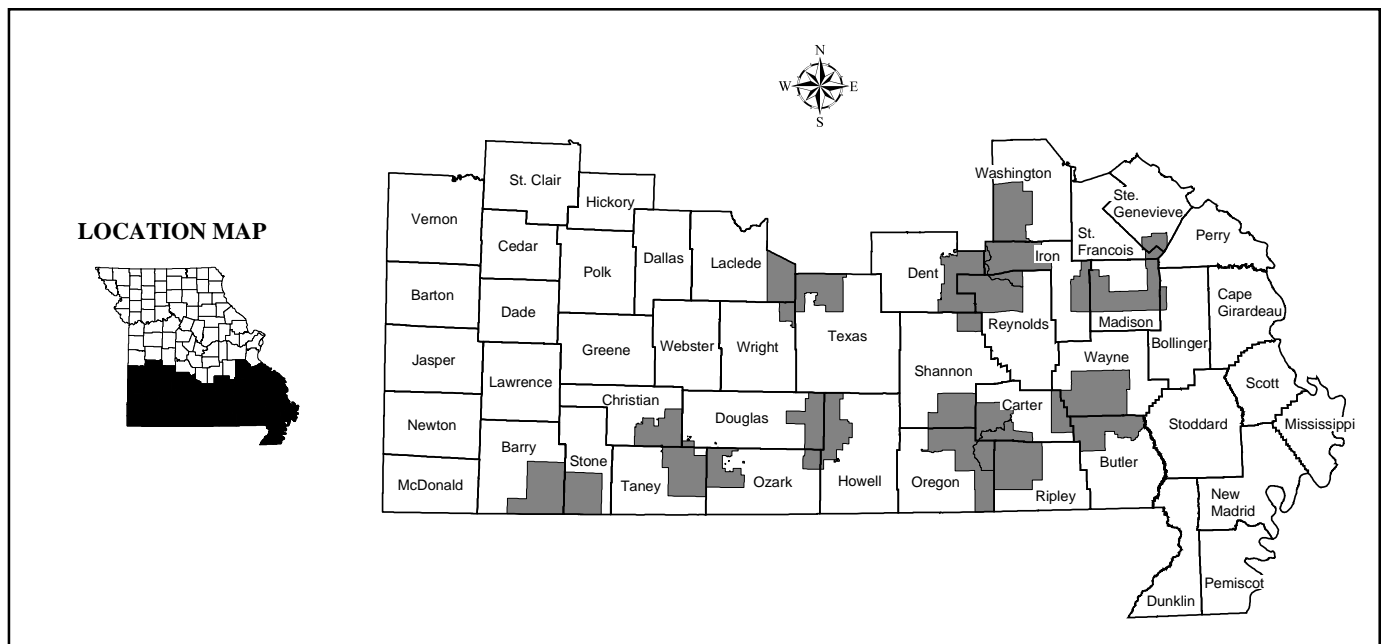


Figure 13. U.S. Forest Service acres in southern Missouri. (Shaded areas represent Forest Service lands.)

logical Survey, analyzed, and used extensively in their National Water-Use Information Program. Most of the water use data provided in this section is referenced from this program (USGS, 2002).

Public Water Supply

The percentage of publicly supplied water in southeastern Missouri allocated to commercial, domestic, and industrial uses is lower than statewide averages. Public water use is often defined as community-wide applications of water, such as firefighting and filling public swimming pools. Public water use also includes transmission losses (water lost from leaking pipes and joints while being delivered to domestic, commercial and industrial users). Approximately 30 percent of southeastern Missouri's publicly supplied water went to public uses in 2000 compared to 27.7 percent statewide.

The percentage of water withdrawn for public supply delivered for domestic use in 2000 was approximately 58 percent compared to 50 percent for Missouri statewide.

Similarly, 2000 commercial use of public water supplies was slightly lower in southeastern Missouri than for the state overall. Commercial water use is defined by the USGS as "water for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions" (Solley, et al., 1993). In 2000, approximately 5 percent of southeastern Missouri's publicly supplied water was delivered to commercial water users compared to 8 percent statewide. Similarly, public water supply deliveries for industrial use in southeastern Missouri were low in 2000. Compared to the statewide figure of 14 percent, industrial water users in southeastern Missouri accounted for only 7 percent of total public water supply usage.

Eighty percent of the population of southeastern Missouri receiving water from public water systems are supplied by groundwater wells compared with a state average of 43 percent. In southeastern Missouri, 65 percent of citizens are connected to a public water supply compared to 85 percent statewide.

Domestic Water Use

Domestic water use is often defined as "water used for household purposes", such as drinking, cooking, bathing, and washing clothes and dishes. The National Water-Use Information Program of the United States Geological Survey (USGS) estimated 2000 domestic water use in southeastern Missouri at 16.1 billion gallons of water. These figures indicate that per capita usage was approximately 80 gallons/day for domestic usage. While three-fourths of southeastern Missouri's domestic water requirements are supplied by public water systems, private water supplies serve much of the area's population. Approximately 190,000 people in southeastern Missouri drew water from private supplies in 2000. The data from 2000 indicates that 100 percent of self-supplied domestic water withdrawals came from groundwater sources, although it is likely that a small percentage of users obtained water from surface water sources. In the 1990 U.S. Census of Population and Housing, approximately 4,600 housing units in southeastern Missouri reported using "some other source" for water, a catch-all category which the Census Bureau defines as "water obtained from springs, creeks, rivers, lakes, cisterns, etc."

Industrial and Commercial Water Use

Industrial water use in southeastern Missouri is low, and accounts for nine percent of public water supply deliveries. The USGS estimated 2000 industrial water withdrawals at 4.8 billion gallons throughout the year. Industrial water users across Missouri typically rely on public supplies rather than self-supplied water. However, in 2000, industrial water users in southeastern Missouri received 1.3 billion gallons of water from public water systems, approximately 22 percent of their total water use. In 2000, 71 percent of total self-supplied withdrawals for industrial use came from groundwater sources. The data indicates varying levels of industrial water use throughout southeastern

Missouri, with 12 out of 24 counties showing little or no industrial water use at all.

In southeastern Missouri, commercial water use is less than industrial water use. Commercial water use in southeastern Missouri totaled nearly 1.2 billion gallons in 2000. Commercial water use in southeastern Missouri depends upon both public water supply deliveries and private supplies, with public water systems supplying approximately 75 percent of the region's commercial water requirements.

Agricultural Water Use

Farmers in southeastern Missouri draw water both to irrigate farmlands and to water their livestock. Water withdrawals for irrigation watering far surpass withdrawals for livestock in southeastern Missouri. Groundwater sources account for most of southeastern Missouri's agricultural water use. In 2000, over 99 percent of the 480 billion gallons of water used for agricultural operations in southeastern Missouri was taken from the region's groundwater, most of which went to irrigation in the Bootheel.

Irrigation water use in southeastern Missouri surpassed livestock water withdrawals in 2000. Three-fourths of livestock water withdrawals were from surface water sources, consistent with the state as a whole. Livestock production is evenly distributed across southeastern Missouri, with individual counties using up to 503 million gallons per year. A variety of livestock is raised in southeastern Missouri, each of which must have access to water throughout the year. Farmers in southeastern Missouri used slightly more than 3.1 billion gallons of water to water their livestock in 2000. Irrigation water use is concentrated in the Bootheel area of southeastern Missouri, with three counties (Butler, Stoddard, and New Madrid Counties) accounting for over 73 percent of the region's irrigation water use.

Less than 1 percent of irrigation withdrawals in southeastern Missouri came from surface water sources in 2000, as compared to the statewide value of 4 percent. It should be noted that

over 90 percent of all of Missouri's irrigation water is used in the Bootheel.

Water Use in Power Production

The Major Water Users Database of the Missouri Department of Natural Resources, estimated total thermoelectric power generation withdrawals in southeastern Missouri at approximately 306 billion gallons of water in 2000 (Missouri Department of Natural Resources, 2001). Withdrawals for thermoelectric power generation are used primarily for power plant cooling and come mainly from surface water sources. Although thermoelectric power generation requires vast amounts of water, very little of it is actually consumed. Statewide, more than 99 percent of all thermoelectric power withdrawals were returned to their source waters. In southeastern Missouri, six facilities (CTG Plant, Cape Girardeau Co.; St. Francis Power Plant in Dunklin Co.; City of West Plains, Howell Co.; St. Jude Industrial Park and New Madrid Power Plants, New Madrid Co., and Sikeston Power Station, Scott Co.) account for the region's thermoelectric power generation. All of the plants get their water from groundwater, except the New Madrid plant, which uses Mississippi River water.

One hydroelectric power generation facility operates in southeastern Missouri, Taum Sauk Plant in Reynolds County. It is a pump-back unit, where excess electrical power at night is used to pump water from a lower retention pond to a higher one, which is then released during the day to generate electricity. This facility used approximately 780 million gallons of water to generate electricity in 2000 (Missouri Department of Natural Resources, 2001). Hydroelectric power generation is generally considered a non-consumptive use of water, although some water is lost every year through evaporation.

Other Instream Flow Uses

Fish and other aquatic organisms in southeastern Missouri's lakes and streams depend upon flowing water for survival and aquatic habitat preservation. Many municipalities in southeastern Missouri rely upon flowing water to safely release wastewater back into the environment. Swimming areas and boat launches found on nearly every body of water within the region accommodate recreational activities throughout most of the year. Although no water is withdrawn, each of these is a "use" of water as well. Collectively, these are often referred to as "instream" uses.

Southeastern Missouri's water resources are known across the state for the recreational opportunities they provide. Wappapello and Clearwater Lakes attract visitors throughout Missouri. In addition, a number of state parks within southeastern Missouri draw upon the region's water resources, including Grand Gulf, Johnston Shut-Ins, Lake Wappapello, Montauk, and Sam A. Baker State Parks, to name but a few. Southeastern Missouri's many rivers and streams offer a variety of recreational opportunities, including fishing and canoeing. Three national scenic rivers (the Current, the Eleven Point, and the Jack's Fork) also draw many water recreationers to the area from around the country.

Preservation of aquatic wildlife and habitat is another important "instream" use of water. Numerous conservation areas maintained by the Missouri Department of Conservation are located in southeastern Missouri. Most of southeastern Missouri falls within the Ozark Aquatic Faunal Region (Pflieger, 1989). Although some upland drainages may become dry during drought conditions, many rivers and streams in southeastern Missouri have permanent streamflow that supports fish and wildlife throughout the year.

Sources:

- Gaffney, R.M., and Hays, C.R., 2000, Water Resources Report Number 51, **A summary of Missouri water laws**, Missouri State Water Plan Series Volume VII, Missouri Department of Natural Resources, Division of Geology and Land Survey, 292 pp.
- Madras, John, Planning Section Chief, Water Pollution Control Program, Department of Natural Resources, Water Protection and Soil Conservation Division, written communication, 2001.
- Missouri Department of Natural Resources, 2001, Geological Survey and Resource Assessment Division, Water Resources Program. **Major Water Users Database**.
- Missouri Department of Natural Resources, 1996, Water Pollution and Soil Conservation Division, **Inventory of Missouri public water systems**.
- Pflieger, William L., 1989, **Aquatic community classification system for Missouri**, Missouri Department of Conservation, Aquatic Series No. 19, 70 pp.
- Solley, W. B., Pierce R. R., Perlman, H. A., 1993, **Estimated use of water in the United States in 1990**, United States Geological Survey Circular 1081, p. 76.
- U. S. Bureau of the Census, 1990, **Census of Population and Housing**.
- USGS water use, 2002; <http://water.usgs.gov/watuse>
- Vandike, James E., 1996, Water Resources Report Number 45, **Surface water resources of Missouri**, State Water Plan Series Volume 1, Missouri Department of Natural Resources, Division of Geology and Land Survey, 122 pp.

Southwestern Regional Water Use Overview

Water Resources Management

There are many issues that confront and hinder water resource managers. See explanation contained in Southeast Region Water Use Overview.

The following description of water use in southwestern Missouri is included to provide context for the water use problems identified in this report. As part of the major Water Users Law (RSMo 256.400), the Department of Natural Resources', Water Resource Program compiles water use information. Major water users are defined as those users that are capable of pumping greater than 100,000 gallons of water per day from either groundwater or surface water. The Major Water Users Database includes information about location, amount of water used, and type of use (domestic, municipal, electrical generation, fish and wildlife, and drainage). This data is submitted to the United States Geological Survey, analyzed, and used extensively in their National Water-Use Information Program. Most of the water use data provided in this section are referenced from this program (USGS, 2002).

Public Water Supply

The percentage of publicly supplied water in southwestern Missouri allocated to commercial, domestic, and industrial is lower than statewide averages. Public water use is often defined as community-wide applications of water, such as firefighting and filling public swimming pools. Public water use also includes transmission losses (water lost from leaking pipes and joints while being delivered to domestic, commercial and industrial users). Nearly 38 percent of southwestern Missouri's publicly supplied water was allocated to public uses in 2000 compared to 28 percent statewide.

The percentage of water delivered in 2000 for domestic use was approximately 44 percent compared to 50 percent for Missouri statewide.

In 2000 commercial use of public water supplies was the same in southwestern Missouri as for the state overall, at 8 percent. Commercial water use is defined by the USGS as "water for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions" (Solley, et. al., 1993). In 2000, approximately 8 percent of southwestern Missouri's publicly supplied water was delivered to commercial water users compared to 8 percent statewide. Similarly, public water supply deliveries for industrial use in southwestern Missouri were low in 2000. Compared to the statewide figure of 14 percent, industrial water users in southwestern Missouri accounted for only 9 percent of total public water supply usage.

Fifty-six percent of the population of southwestern Missouri receiving water from public water systems are supplied by groundwater wells compared with a state average of 43 percent. In southwestern Missouri, 63 percent of citizens are connected to a public water supply.

Domestic Water Use

Domestic water use is often defined as "water used for household purposes", such as drinking, cooking, bathing, and washing clothes and dishes. Excluding thermoelectric and hydroelectric power generation, domestic water use is the predominant use of water in southwestern Missouri. The National Water-Use Information Program of the United States Geological Survey estimated 2000 domestic water use in southwestern Missouri at 26.4 billion gallons of water. These figures indicate that per capita usage was approximately 87 gallons/day for domestic usage. While 70 percent of southwestern Missouri's domestic water requirements are supplied by public water systems, private water supplies serve much of the area's population. Approximately 308,000 people in southwestern Missouri drew water from private supplies in 2000. The data from 2000 indicates that 100 percent of self-supplied domestic water withdrawals came from groundwater sources, although it is likely that a small percentage of users obtained water from surface water sources. In the 1990 U.S. Census of Population and Housing, approximately 2,600 housing units in southwestern Missouri reported using "some other

source” for water, a catch-all category which the Census Bureau defines as “water obtained from springs, creeks, rivers, lakes, cisterns, etc.”

Industrial and Commercial Water Use

Industrial water use in southwestern Missouri is low, and accounts for less than 9 percent of public water supply deliveries. The USGS estimated 2000 industrial water withdrawals at 6 billion gallons throughout the year. Industrial water users across Missouri typically rely on public supplies rather than self-supplied water. In 2000, industrial water users in southwestern Missouri received 3.5 billion gallons of water from public water systems, approximately 60 percent of their total water use. In 2000, nearly 80 percent of total self-supplied withdrawals for industrial use came from groundwater sources. The data indicates varying levels of industrial water use throughout southwestern Missouri, with 12 out of 22 counties showing little or no industrial water use at all.

In southwestern Missouri, commercial water use is less than industrial water use. Commercial water use in southwestern Missouri totaled nearly 4.4 billion gallons in 2000. Commercial water use in southwestern Missouri depends upon both public water supply deliveries and private supplies, with public water systems supplying approximately 75 percent of the region’s commercial water requirements.

Agricultural Water Use

Farmers in southwestern Missouri draw water both to irrigate farmlands and to water their livestock. Water withdrawals for irrigation watering surpass withdrawals for livestock in southwestern Missouri, similar to the rest of the state. Surface water sources account for most of southwestern Missouri’s agricultural water use. In 2000, 58 percent of the 19.2 billion gallons of water used for agricultural operations in southwestern Missouri was taken from the region’s lakes and streams.

Irrigation water use in southwestern Missouri surpassed livestock water withdrawals in

2000, with usage exceeding 11.5 billion gallons of water. Three-fourths of livestock water withdrawals were from surface water sources, consistent with the state as a whole. Livestock production is evenly distributed across southwestern Missouri, with individual counties using up to 540 million gallons per year. A variety of livestock is raised in southwestern Missouri, each of which must have access to water throughout the year. Farmers in southwestern Missouri used slightly more than 7.7 billion gallons of water to water their livestock in 2000. Irrigation water use is widely distributed across southwestern Missouri, but three counties (Barton, Jasper, and Vernon Counties) account for over 65 percent of the region’s irrigation water use.

Approximately half of irrigation withdrawals in southwestern Missouri came from surface water sources in 2000, in sharp contrast to the statewide value of 4 percent.

Water Use in Power Production

The Major Water Users Database of the Missouri Department of Natural Resources estimated total thermoelectric power generation withdrawals in southwestern Missouri at approximately 74 billion gallons of water in 2000 (Missouri Department of Natural Resources, 2001). Withdrawals for thermoelectric power generation are used primarily for power plant cooling and come mainly from surface water sources. Although thermoelectric power generation requires vast amounts of water, very little of it is actually consumed. Statewide, more than 99 percent of all thermoelectric power withdrawals were returned to their source waters. In southwestern Missouri, three facilities (James River Power Station and Southwest Power Station, both in Greene County, and Asbury Power Station in Jasper County) account for the region’s thermoelectric power generation. The James River plant uses surface water, whereas the other two plants have wells.

Three hydroelectric power generation facilities operate in southwestern Missouri: Stockton Dam in Cedar County, and Powersite and Table Rock Dams in Taney County. Together, these three facilities used approximately 0.7 tril-

lion gallons of water (2,148 acre-feet of water) to generate electricity in 2000 (Missouri Department of Natural Resources, 2001). The power generated by these three plants in 2000 is as follows: Ozark Beach (Powersite Dam) = 16 mega watts, Table Rock = 1,181.5 mega watts, and Stockton = 45.2 mega watts. Hydroelectric power generation is generally considered a non-consumptive use of water, although some water is lost every year through evaporation and seepage from reservoirs.

Other Instream Flow Uses

Fish and other aquatic organisms in southwestern Missouri's lakes and streams depend upon flowing water for survival and aquatic habitat preservation. Many municipalities in southwestern Missouri rely upon flowing water to safely release wastewater back into the environment. Swimming areas and boat launches found on nearly every body of water within the region accommodate recreational activities throughout most of the year. Although no water is withdrawn, each of these is a "use" of water as well. Collectively, these are often referred to as "instream" uses.

Southwestern Missouri's water resources are known across the state for the recreational opportunities they provide. Table Rock and Taneycomo Lakes attract visitors from throughout the Midwest, along with Bull Shoals, Norfolk, Pomme de Terre, and Stockton Reservoirs. In addition, a number of state parks within southwestern Missouri draw upon the region's water resources, including Bennett Springs State Park, Pomme de Terre State Park, Roaring River State Park, Stockton State Park, and Table Rock State Park. Southwestern Missouri's many rivers and streams offer a variety of recreational opportunities, including fishing and canoeing.

Preservation of aquatic wildlife and habitat is another important "instream" use of water. Numerous conservation areas maintained by the Missouri Department of Conservation are located in southwestern Missouri. Most of southwestern Missouri falls within the Ozark Aquatic Faunal Region (Pflieger, 1989). Although some upland drainages may become dry during drought conditions, many rivers and streams in southwestern Missouri have permanent streamflow that supports fish and wildlife throughout the year.

Sources:

Gaffney, R.M., and Hays, C.R., 2000, Missouri State Water Plan Series Volume VII, **A Summary of Missouri Water Laws**, Water Resources Report Number 51, page 50 of 292 pp., Missouri Department of Natural Resources, Division of Geology and Land Survey.

Madras, John, Planning Section Chief, Water Pollution Control Program, Department of Natural Resources, Water Protection and Soil Conservation Division, written communication, 2001.

Missouri Department of Natural Resources, 2001, Geological Survey and Resource Assessment Division, Water Resources Program, **Major Water Users Database**.

Missouri Department of Natural Resources, 1996, Water Pollution and Soil Conservation Division, **Inventory of Missouri Public Water Systems**.

Pflieger, William L., 1989, **Aquatic Community Classification System for Missouri**, Missouri Department of Conservation, Aquatic Series No. 19, 70 pp.

Solley, W. B., Pierce R. R., Perlman, H. A., 1993, **Estimated Use of Water in the United States in 1990**, United States Geological Survey Circular 1081, p. 76.

U. S. Bureau of the Census, 1990, **Census of Population and Housing**.

USGS water use, 2002; <http://water.usgs.gov/watuse>

Vandike, James E., 1996, State Water Plan Series Volume 1, **Surface Water Resources of Missouri**, Water Resources Report Number 45, 122 pp. Missouri Department of Natural Resources, Division of Geology and Land Survey.



Water Use Problems

Drinking Water Use

Groundwater Assessment Needed

Problem:

In order to maintain the quantity and adequate quality of our groundwater resources, we need a comprehensive county by county groundwater assessment in the state to help manage the resource.

Discussion:

Although much is known about Missouri's groundwater, as evidenced by Water Resources Report # 46, *Groundwater Resources of Missouri*, much more detailed information is needed. The authors of this report state that "this report is an overview of the groundwater resources of Missouri" (Miller and Vandike, 1997).

Groundwater is used extensively throughout most of southern Missouri, for many purposes, including drinking water, irrigation, industrial purposes, etc. Unlike surface water, where streams or reservoirs are relatively easy to quantify, aquifers are more difficult to assess because one can't directly see their entire extent and physically measure the resource.

Utilizing a county framework will help to focus on the specific areas that need assessment immediately due to groundwater use issues that have already occurred. But, it needs to be stated that most of the following assessment components do not adhere to political boundaries but deal with subsurface geology, which is irrespective of county boundaries.

Study and continuing data generation on the following assessment components is necessary to enable coherent scientific based decisions, both present and future, to be made concerning groundwater resources:

1. Groundwater Use - the amount or number of gallons of groundwater used is necessary for all user types. This must include consumptive and non-consumptive uses. The analysis of the historical data is necessary to show groundwater use trends. Presently, the Major Water User law (section 256.400 to 256.430 RSMo) which was passed in 1983, requires major water users (capability to produce at least 100,000 gallons of water per day) to register their use each year with the Department of Natural Resources, Geological Survey and Resource Assessment Division. Compliance with this law is at issue because of a lack of penalty provisions for users who do not follow the law. Complete information is not being gathered.

A compliance strategy needs to be created to ensure full reporting. Also, no requirement exists for less than 100,000 gallon per day users. This information is necessary to get a thorough picture of present groundwater use. It is also important to register usage because if Missouri's water law changes in the future from "riparian" to "prior appropriation" water rights, the water registration of a user would help determine the "first in time" stipulation of prior appropriations water law. This would become important in the future if water demand were higher than water availability.

2. Groundwater Level Measurements - the volume of groundwater in storage varies de-

pending on rainfall, water use, and other factors. Groundwater storage is monitored by measuring the water level in aquifers. Beginning in the 1950's, information on Missouri's groundwater levels were gathered by the Geological Survey and Resource Assessment Division. This system of groundwater monitoring wells was begun in the 1950's due to the extended drought that occurred during that time which caused serious water supply conditions. It has been in operation since then and was expanded to 70 wells in 2002.

Each of the observation wells is equipped with an electronic data collection platform. The heart of the installation is a data recorder that is essentially a dedicated computer. It receives data from a water level sensor and stores that information. A water-level value is recorded every 30 minutes. Every four hours, each station has a one-minute time window when it can transmit the recently-collected data back to the office using data channels in a GOES weather satellite that is in geostationary orbit about 22,000 miles above the equator. This results in data not more than about four hours old being accessible to anyone with access to the Internet.

The data is stored in the U.S. Geological Survey ADAPS data storage system. The USGS also hosts the Internet site where the data can be accessed. This site can be accessed at www.dnr.mo.gov/water.htm then under the category "monitoring" select "Current Groundwater Conditions". Although Missouri's monitoring well system has been developing historical groundwater level data for approximately 50 years, much more needs to be done in this area. Many more wells need to be placed across Missouri to add to this database on groundwater level measurement.

3. Recharge Area - another area that needs to have a comprehensive ongoing assessment is the relationship between surface water and groundwater. When it rains how does the surface water get into the ground or does it all run off into surface streams and rivers. Much of southern Missouri has abundant

sinkholes, caves, losing streams and springs (collectively known as karst). This forms because of the regions predominant carbonate rock type (dolomite and limestone) which can be dissolved by water, thereby forming these types of structures. Sinkholes and losing streams can act as direct conduits to move surface water to groundwater quickly (much faster than happens where water must slowly percolate through layers of soil and rock).

Since the karst features are constantly being shaped by moving water, they are always changing (although, usually at a rate too slow for humans to observe). But in some cases dramatic changes can occur rapidly. For example, the city of West Plains lost the contents of their sewage lagoon overnight in 1978, due to the opening up of a sinkhole. Apparently, they had constructed the municipal lagoon over the sinkhole that they did not know existed.

There is also the problem of perception leading to false assumptions. Often, springs have clear cold water flowing into a beautiful area that appears pristine. However, due to the nature of the quick movement of water from surface to groundwater (thereby bypassing the filtering and cleansing properties of soil and rock), there is no guarantee that springs are contaminant-free, although they may appear so.

In addition to the quantity of water in aquifers, potential vectors of contamination are important to understand so that appropriate protection can be established. Water is recharged into aquifers through the surface of the earth, with some locations contributing proportionately more recharge than others. These locations may require special land use measures to ensure the quality of the recharge is maintained. It is similarly difficult to understand recharge characteristics (how much goes into the aquifer over a given period of time, and if there are areas that have proportionately greater affect on the amount of water entering the aquifer) as it is the characteristics of the aquifer itself. Once an aquifer is polluted, it is very difficult and expensive to clean up.

Knowing exactly where the pollution is, where it is headed, and how fast it is moving are difficult questions to answer.

The Geological Survey and Assessment Division has conducted ongoing work in many areas that partly address these questions. They include: study of the geology, water traces to determine the recharge areas of springs, losing stream inventory, springs database, sinkhole inventory, etc. What is needed is a focused expansion of these studies and databases. Additionally, putting the data into a format that can be used by decision-makers would be most useful. Utilizing Geographic Information System (GIS) technology would help unravel the complicated interrelationships between all these features.

4. Aquifer Geology - another assessment tool, would provide extensive geologic detail, including extent of aquifers, both lateral and vertical with effective porosity and permeability percentages. This would allow calculations to be made showing how much water was in each aquifer and how much water could be produced from the aquifer. Although the Geology Survey and Assessment Division has been the repository for geological knowledge since 1853 much more needs to be done in the areas noted above.

Sources:

Miller, Don E., and Vandike, James E., 1997, Water Resources Report Number 46, **Groundwater resources of Missouri**, Missouri State Water Plan Series Volume II, Missouri Department of Natural Resources, Division of Geology and Land Survey, 210 p.

Vandike, James E., Groundwater Section Chief, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, November, 2002.

Overuse of Groundwater in Site Specific Areas

Problem:

There are several areas in Missouri where the overuse of groundwater has led to declining groundwater levels. When a well is pumped, the water level in the well is lowered, which induces water in the aquifer adjacent to the well to flow into the well. The difference between the static or non-pumping water level in a well, and the water level at the end of the pumping cycle, is called the drawdown. The drawdown depends on the pumping rate, the pumping period, and the hydrologic characteristics of the aquifer such as its thickness, hydraulic conductivity, and storage coefficient. The drawdown is greatest in the pumped well, and decreases with distance from the well. A well producing a large quantity of water for a long period of time can develop a substantial "cone of depression" or "drawdown cone" around the well. The cone of depression that forms around a high-yield well that is pumped for an extended period may extend several thousand feet or more from the well. The distance from the pumped well to the edge of the cone of depression is called the radius of influence. When pumping ends, the water level in the well begins to rise and the cone of depression begins to decrease in size. If there is ample time between pumping cycles, the well will fully recover and water level will return to its pre-pumping level (figure 14).

Well interference results when the drawdown cones of multiple pumping wells merge. If drawdown cones of two wells overlap, the result is increased drawdown in both wells as compared to the drawdowns generated by the individual wells. Spacing wells as far apart as possible reduces well interference. Groundwater-level declines often occur where there are numerous high-yield wells producing within a relatively small area such as a municipal well field, industrial park, irrigation area or confined animal feeding operation. As long as the production wells are of similar depth, well interference typically is not an immediate or major problem. However, in areas where relatively shallow domestic wells are drilled into the same aquifer as

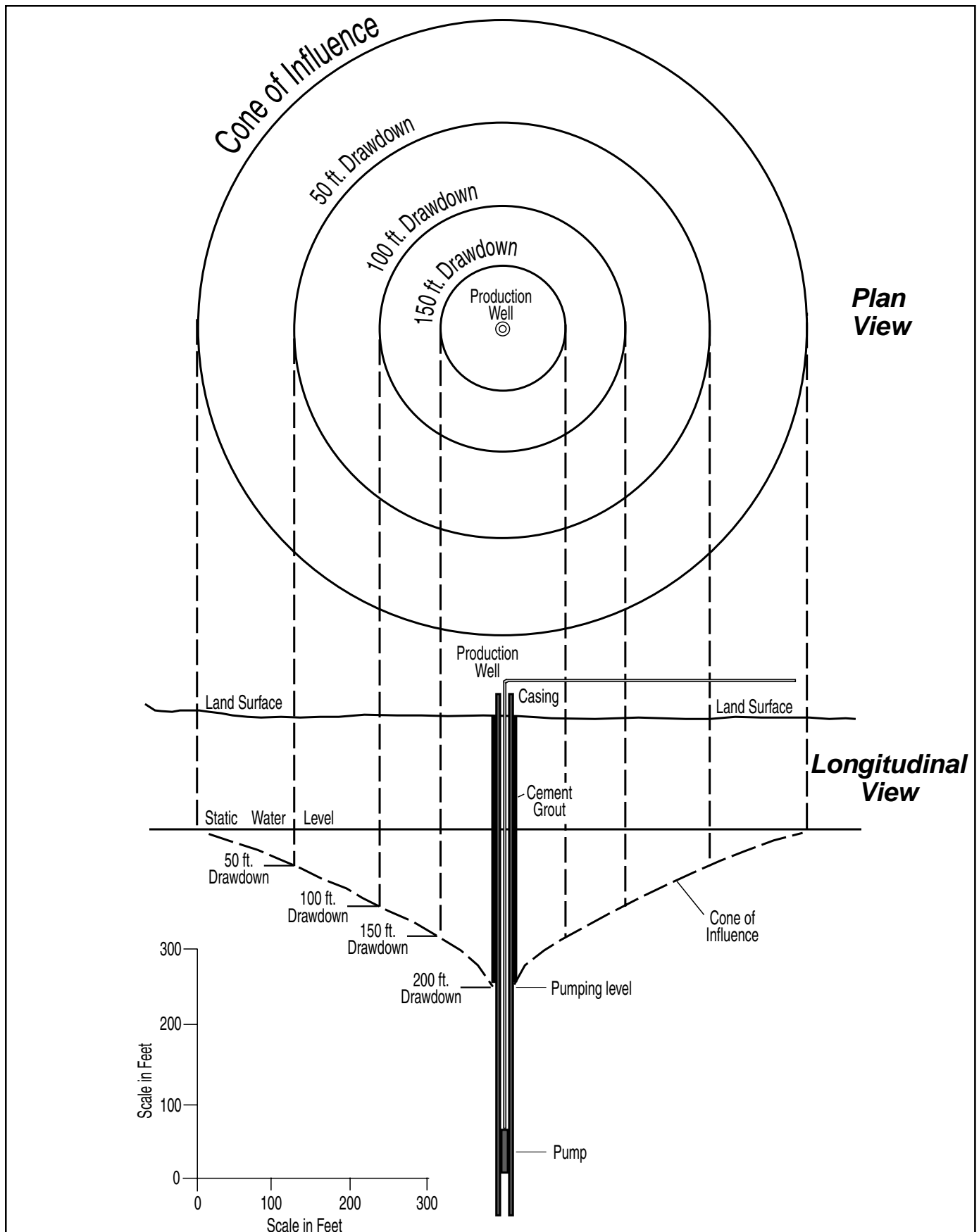


Figure 14. Idealized "cone of depression" from pumpage of a high-yield well.

deep high-yield wells, production by the high-yield wells may lower water levels to the point that the shallow wells will no longer function. There is no statute to assure that earlier users are not harmed by later users.

Discussion:

Groundwater is water beneath the earth's surface within a zone of saturation. The upper surface of the zone of saturation in an unconfined aquifer is called the water table. Layers of rock and other geologic materials capable of transmitting and storing economically significant quantities of water are called aquifers. Groundwater is a finite resource that is ultimately replenished by precipitation soaking into the earth. Each water well has a source-water area that supplies it. Depending on geology and well construction, some wells receive their recharge entirely from infiltration of precipitation into the earth within its source water area. Others may not be appreciably affected by local rainfall, but rely on lateral movement of groundwater from a more substantial distance.

Although it is a finite resource, groundwater is also a renewable resource. However, groundwater recharge can be a slow process. The time it takes to replenish a given volume of groundwater in the earth depends on many factors including the porosity and hydraulic conductivity of the earth materials, aquifer depth, presence of confining units, precipitation, and area groundwater withdrawal rates. Relatively shallow unconfined aquifers are typically more readily recharged than deeper confined aquifers. In some cases, groundwater may take years to move only a few feet, while in the karst terrain of southern Missouri, groundwater flowing through major spring systems may travel a mile or more per day through solution-enlarged openings in the carbonate bedrock. Recharge rates may be less than 1 inch of water per year (33 gallons per minute per square mile) in low-permeability glacial drift and Pennsylvanian-age bedrock north of the Missouri River, to more than 12 inches of water per year (400 gallons per minute per square mile) in the karst water-

sheds in the southern part of the region. Where groundwater extraction exceeds recharge there is a net loss of water in storage and the water level in the aquifer will decline proportionally. Groundwater recharge can also be decreased in urban areas due to pavement and buildings, which increase the amount of impervious surface area.

Groundwater availability and potability vary with location across the region. In most areas of the region, however, large quantities of high-quality groundwater is readily available and is sufficient to provide for municipal, agricultural, and industrial uses. Under certain conditions, such as in low groundwater yield areas or areas of high groundwater production; the rate that water is being extracted exceeds the recharge rate. This can lower groundwater levels and affect groundwater availability, especially in shallower wells. Excessively lowering groundwater levels will negatively affect water supply economics in the area. Pumping costs will increase, wells ultimately may need to be deepened or abandoned, or in extreme cases alternative water supplies may eventually need to be developed.

Lowering groundwater levels can have a negative effect on spring discharge and stream base flow contributions. Which in turn could impact aquatic life, especially any rare, threatened and endangered species that are reliant on groundwater (ie. Ozark cavefish etc.).

Some of the major aquifers in southern Missouri serve private homes and public water supply districts, and supply water for agriculture and industry. Missouri usually has enough snow and rainfall to replenish the water supply in most aquifers, but during years of drought, water levels in many aquifers decline. Voluntary water conservation is common during droughts. Missouri has no statute that requires curtailment in certain circumstances but the Missouri Drought Plan sets out a method to address drought and its effects. However, citizens can file suit under the "reasonable use" doctrine to curtail what is alleged to be unreasonable or excessive use.

Site Specific Examples:

“For many years, there has been a slow, steady decline of the Ozark aquifer potentiometric surface in southwestern Missouri from about McDonald County to Jasper County. Since 1962, groundwater levels have been monitored in this area using an abandoned municipal well at Noel in McDonald County, near the southwest corner of the state. The well is 850 ft. deep and is open to the Cotter and Jefferson City dolomites and the Roubidoux Formation. It contains 99 ft. of casing, and is cased through the Chattanooga Shale. When this well was drilled in 1931 for the Noel Water Company, it was a flowing artesian well that discharged about 60 gpm without pumping. Static water level of the well was several feet above land surface. Water level in the well decreased to the point that it ceased flowing in the late 1950s. In May of 1962 when it was converted into an observation well, depth to water in the well was 48.7 feet. In 1997 the water level in the observation well was about 270 feet below land surface” (Miller and Vandike, 1997). In November 2002 the water level averaged about 430 below ground surface (figure 15) (Vandike, 2002).

“Much of the water-level decline is thought to be due to municipal well pumpage at Miami, Oklahoma, about 24 miles northwest of Noel. However, during the past two decades there has been considerable groundwater use a few miles south of Noel at large retirement developments in northern Arkansas, as well as from large poultry operations in the McDonald County area. Estimates indicate that the Ozark aquifer is the most significant aquifer in the Springfield Plateau groundwater province. It contains an estimated 112.6 trillion gallons, or about 346 million acre-feet of usable water” (Miller and Vandike, 1997).

The City of Branson in Taney County experienced declining groundwater levels in the early to mid 1990's. This was the time that area tourism was at its peak and the tourism 'off season' became shorter. Historically, it was during the 'off season' that groundwater usage decreased and groundwater levels typically recovered. Prior to this period, most deep wells were drilled to total depths of around 1500 feet, which

placed the bottom of the well in the Eminence Dolomite. However, the area's rapid growth of the early 1990's led to the construction of more and deeper wells resulting in further lowering of groundwater levels. Because groundwater levels were declining so rapidly, new municipal wells were drilled deeper. Adequate water quantities are available from the Ozark aquifer at great depth, but it quickly becomes economically infeasible to pump and deliver. Branson was fortunate to have a ready surface water source nearby in Lake Taneycomo. The city chose to develop an additional surface water treatment plant and use surface water to supply the bulk of their water demand. Since completion of the new treatment plant, groundwater levels steadily recovered and are currently at or above pre-1990 levels in the immediate Branson area (Brookshire, 2003).

Springfield, in Greene County Missouri has been experiencing declining water levels for quite some time. Studies by the U. S. Geological Survey in the late 1980's determined that a cone of depression centered on Springfield indicated a 500-foot decline in groundwater levels compared to levels prior to extensive pumping. Although the city's water supply is mostly from surface water sources, there are numerous industrial users that pump water from the Ozark aquifer. Each well drawing water from this aquifer has its own cone of depression, and many of these are in close proximity to other similar wells so that the subsequent cones of depression coalesce to form large regional cones of depression. In addition to this occurrence, new laws governing the construction of domestic wells in Greene and part of Christian counties further complicate the problem because domestic users are required to seal out the upper aquifer and draw water from the same Ozark aquifer utilized by municipal and industrial users. The consequences of this requirement have recently been illustrated just beyond Springfield in northeastern Greene County. It is an area of small acreages where homeowners depend upon domestic wells for water supply. In addition, it is an area that has several industrial users and one main municipal user of the Ozark aquifer. Several hundred domestic wells and numerous industrial wells have been drilled in this area that

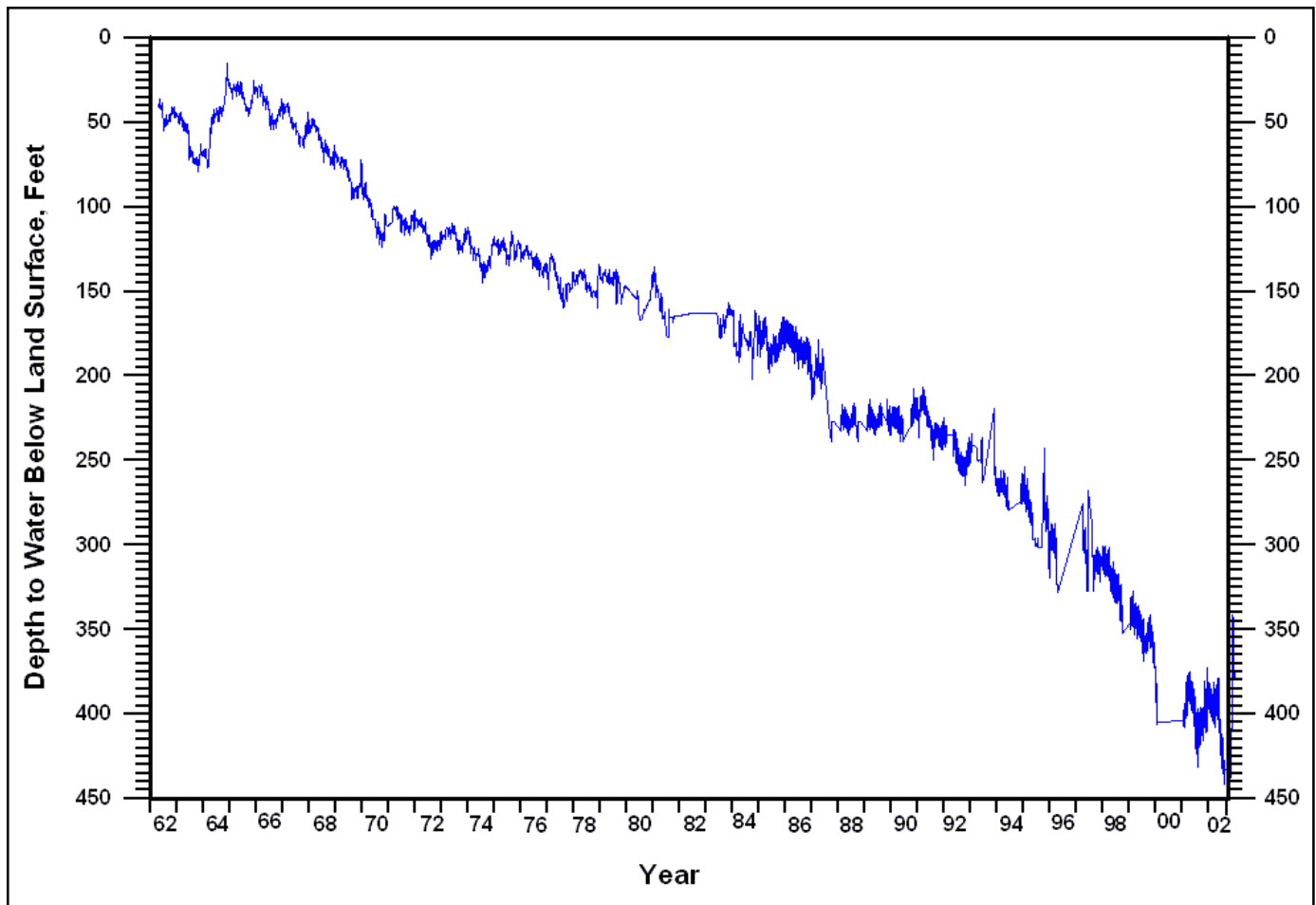


Figure 15. Groundwater-level hydrograph, Noel observation well, McDonald County.

measures approximately one township, or 36 square miles. Since the summer of 2000, domestic well owners there have experienced continued declines in groundwater levels in their wells, sometimes to the point of rendering the well useless (Brookshire, 2003).

Sources:

Brookshire, Cynthia; Hydrologist, Geological Survey and Resource Assessment Division, Department of Natural Resources. Personal written correspondence, January, 2003.

Miller, Don E., and Vandike, James E., 1997, Water Resources Report Number 46, **Groundwater resources of Missouri**, Missouri State Water Plan Series Volume II, Missouri Department of Natural Resources, Division of Geology and Land Survey, 210 p.

Vandike, James E., Groundwater Section Chief, 2002, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, website - Current Groundwater Conditions, www.dnr.mo.gov/geology/wrp/grdh2o.htm

Unplugged Abandoned Wells

Problem:

Historically, most abandoned wells have not been plugged. Abandoned wells are a hazard to people and livestock, and an entry point for surface waters that may carry contaminants into the groundwater. Rules requiring the plugging of wells were established in late 1987, and generally do not apply to wells abandoned before that time. Therefore, there are hundreds of thousands of wells, abandoned since Missouri was settled, that have not been properly plugged.

Discussion:

It has been estimated that Missouri has from 150,000 to 300,000 unplugged abandoned wells. This may be a conservative estimate. After looking into the origin of this estimate, it could easily be at least 500,000 unplugged wells and cisterns scattered across Missouri (Netzler, 2001). If the 500,000 number is used, then there could be approximately 202,000 unplugged wells in the region covered by this report. Each of these unplugged wells or cisterns is a danger either to the health, welfare and safety of Missourians, or to the groundwater that we rely on so heavily for our water resources.

Many things have changed since Missouri's early settlement days more than 200 years ago, but one thing that has not changed is the need for a dependable supply of water (Department of Natural Resources, 1988). If early settlers did not live near a river, spring, lake, or stream, they had to dig a well or cistern. Unlike wells that produce water, cisterns simply store water, filled by runoff from roofs and channeled by gutters and downspouts.

The first wells were hand-dug, and many of them are still in existence today but are rarely used, and often forgotten. A hand-dug well is typically five to ten feet in diameter, and up to fifty feet deep. These wells were lined with local rock or brick and were covered with a concrete or wooden cap. (The biggest hand-dug well in the U.S. is located in southwestern Kansas in the town of Greensburg and is 32 feet in diameter and 109 feet deep.) These types of

wells are considered a major danger to life and limb. People have died in Missouri by accidentally falling into one of these hand-dug wells. These types of tragedies can be avoided with a little preventive action: plugging the well.

Unplugged abandoned drilled wells are also a danger to personal safety and a potential conduit for surface-derived pollutants. The sizes of Missouri's drilled wells range from the normal six-inch diameter for a private domestic well, upwards to 36 inches in diameter. Many people do not realize that a well as small as eight inches in diameter can be a death trap to young children. Some people still remember the drama that played out on our television sets in October, 1987, about a little girl named Jessica McClure who was trapped in a well in Texas. The well was just eight inches in diameter. She was very lucky to have been rescued alive.

Fewer people today live in rural areas, then when those early wells were dug. Additionally, many rural areas today are served by public water supply systems. Usually, when a water supply system is built in an area, people hook onto the system and the wells are abandoned, but not properly plugged. There is a statute (Section 256.628, RSMo) that requires well owners, when they connect to a public water supply, to report if they will be using their water well. If they are not going to use the well, then it must be plugged. Usually, the well owner states that they will use the well in the future, and therefore do not plug the well. In reality, many of these wells are never used again and over the years the well is forgotten and added to the number of unplugged abandoned wells. Follow-up and enforcement of this statute is extremely difficult.

Another example of wells not being plugged properly can be illustrated by the following scenario. A state employee was investigating a lakeside resort and discovered that the facility had been razed. Two water wells had served the resort. Remnants of one well remained, with a rock placed on top of the casing to block the opening. The other well was covered with soil, and it could not be determined from site examination if the well had been properly plugged. The statute requires that the well plugging follow certain procedures, and be registered with

the department's Geological Survey and Resource Assessment Division. Plugging abandoned wells is the responsibility of the landowner, who is liable for accidents.

The definition of an abandoned well, as it appears in Section 256.603 (1), RSMo, of the Water Well Driller's Act, is as follows: "Abandoned well," a well shall be deemed abandoned which is in such a state of disrepair that continued use for the purpose of thermal recovery or obtaining groundwater is impractical and which has not been in use for a period of two years or more. The term "abandoned well" includes a test hole or a monitoring well which was drilled in exploration for minerals, or for geological, water quality or hydrologic data from the time that it is no longer used for exploratory purposes and that has not been plugged in accordance with the rules and regulations pursuant to Sections 256.600 to 256.640. This definition is ambiguous and seemingly open-ended, so it is extremely hard to determine when a well is technically abandoned. Also, if a landowner does not cooperate or "agree" to plug abandoned wells on owned property, the only enforcement that can be done is to refer the party to the Attorney General's Office for litigation. Litigating against large numbers of property owners who have abandoned wells on their property is not the most efficient or cost effective way to accomplish the goal of having all abandoned wells plugged.

Sources:

Netzler, Bruce, (former Section Chief), Wellhead Protection Section, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, 2001.

Missouri Department of Natural Resources, Division of Geology and Land Survey, "Eliminating an Unnecessary Risk: Abandoned Wells and Cisterns," Brochure 1, 1998.

Private Water Well Construction and Water Quality

Problem:

Quality of drinking water from private wells: before enactment of the Water Well Drillers' Act (Sections 256.600 to 256.640, RSMo) and the Missouri Well Construction Rules, in 1987, there were no set standards for private domestic water well construction. Inadequate well construction could lead to water quality problems and could affect human health.

Discussion:

State statutes and rules establish water well construction standards for private water wells, with the goal of protecting both consumers and Missouri's groundwater. The natural quality and quantity of groundwater varies considerably across the southern region, ranging from abundant high quantity and quality to mineralized or muddy water of limited quantity. In some areas, past land uses have caused contamination of aquifers with pollutants. Because of these factors, statutes cannot guarantee water from a properly constructed well will be of high quality. The water well construction rules are designed to ensure that surface contamination does not enter the well, contaminating it and the aquifer (Department of Natural Resources Web Site, 2000).

The most important features concerning proper well construction are that enough casing is used in the well shaft, and that the annulus of the well is grouted. (The space between the outside of the casing and the drilled hole is called the annulus). In the years prior to the well construction rules (pre-October, 1987), there were no requirements on the minimum amount or type of casing that must be used. It is not uncommon to encounter "old wells" that have ten feet of rusted-out "stove pipe casing" (Netzler, 2001). Generally speaking, the casing should seal out the soil and unconsolidated material, and be set into good, solid bedrock. In the southern Missouri region minimum well casing re-

quirements vary greatly. Well casing requirements are based on the geology of the area. Since southern Missouri has diverse geology it also has diverse well casing requirements. Figure 16 shows the areas across Missouri that have separate well construction rules based on the local geology and groundwater availability. Casing requirements range from 20 feet in Area 5

of the Missouri Bootheel to 420 feet in Sensitive area C around Springfield.

Grouting the annulus of a well is of utmost importance. When a private domestic well is drilled in this region, usually an eight and five-eighths inch (8 5/8") diameter hole is drilled to the required casing point. Then the six-inch nominal casing is set into the hole. Since the

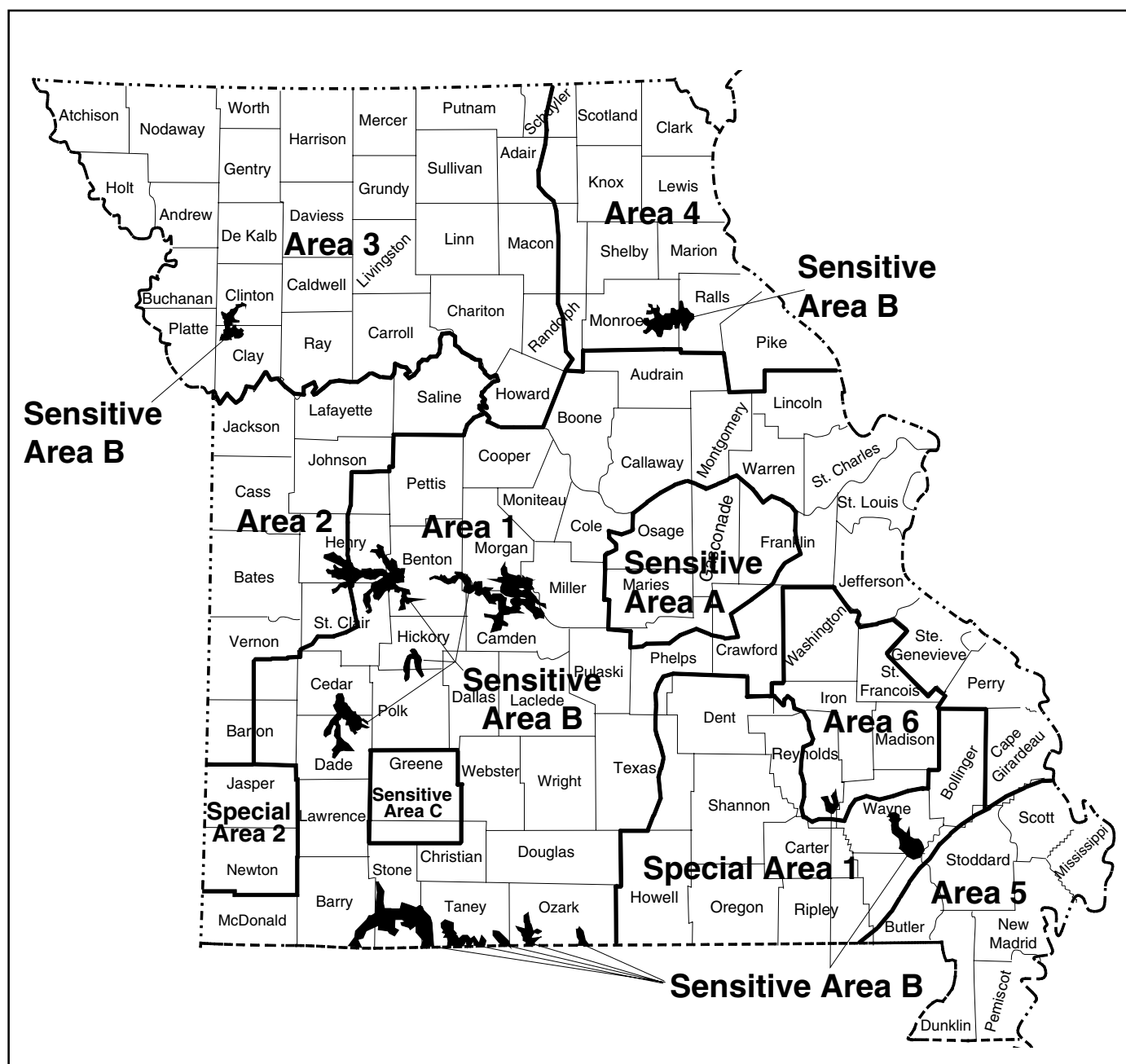


Figure 16. Map showing drilling areas for private well construction regulations.

casing has a smaller diameter than the drilled hole, the space left after the casing is installed must be sealed. This space, the annulus, must be grouted, according to the Missouri Well Construction Rules.

Whenever surface contamination (pesticides, septic tank effluent, animal waste, chemicals, petroleum products, solvents, etc.) finds an ungrouted annulus of a well, it can quickly bypass the natural filtering system of soil, unconsolidated material and rock, and directly contaminate the underground sources of water, the aquifers. Once an underground aquifer is contaminated, it is very difficult and very expensive to clean up. Prevention is always cheaper and more effective than remediation. For example, when septic tank effluent comes in contact with the ungrouted annulus of a well, the water will test positive for fecal coliform bacteria (Netzler, 2001).

The quality of the drinking water produced by these wells is very dependent on how well the annulus has been grouted. Enforcement of how these wells are grouted is a problem. The present regulatory system operates on an after-the-fact reporting requirement based on self-reporting. The permitted well driller has sixty days to report how the well was constructed. Since the regulatory agency, (the department's Geological Survey and Resource Assessment Division) does not know when and where a well is to be drilled, it cannot have staff present to insure that wells are grouted properly (Netzler, 2001).

Domestic water wells installed after 1987 must comply with Section 256.600 to 256.640, RSMo (The Water Well Drillers' Act). However, once installed, there are no requirements for maintenance of these wells. The Centers for Disease Control (CDC) Nine-State Well Survey, completed in 1994, gives very good background information on the state of water quality produced from private wells. The CDC Survey was initiated after the flood of 1993 (on the Missouri River) submerged many wells located in the flooded areas. Questions were raised about the impact of inundation upon well water quality. This study was conceived because little background information existed on a statewide basis. Through the efforts of the nine flooded states

(Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin) and the CDC, this study plan was presented to the U.S. Public Health Office, Office of Environmental Protection, and ultimately was funded by that organization.

The CDC Study systematically placed a grid of longitude/latitude intersections across the entire state of Missouri, with a minimum of eight sample sites for every county. Sampling personnel were to locate and obtain a sample from one private domestic water well within a three-mile radius of each intersection. This sampling method provided a true cross-section of well type and construction. The only criterion was that each well had to be used for drinking water purposes. Each sample taken was tested for bacteria, nitrate, and atrazine contamination. Figure 17 shows the results of the bacteria tests for the counties in the southern Missouri region.

The CDC Study tested for two types of bacteria. The first is a group of bacteria called Coliform. This type of bacteria is present in soils and at the surface of the ground. This is an indicator bacterium which suggests that these bacteria have gone from the surface into the subsurface either by way of an ungrouted annulus, improper well cap, or an unplugged abandoned well. The second type of bacteria tested for was of the subgroup called fecal coliform, specifically the potential disease causing E-coli strain. Fecal coliform bacteria represent a group of bacteria commonly found in the intestinal tract of warm-blooded animals.

Approximately 56 percent of the wells tested in the southern Missouri region tested positive for coliform bacteria and 17 percent tested positive for E-coli bacteria. The average age of these wells was 24 years, and the average depth was 212 feet, with 59 percent showing poor construction features. For drilled wells, a number of factors were significantly associated with coliform results: depth, age, diameter, type of casing, whether or not the well had a cap, type of pump installed with the well, and proximity to a septic tank leach field. Well depth over one hundred feet, age less than eight years (remember, this was done in 1994), and plastic or steel casing were associated with significantly lower positive coliform percentages. Addition-

Seismic Activity

Problem:

A major earthquake in the southeast Missouri region could have disastrous results on drinking water supplies, wastewater systems, and local ecosystems.

Discussion:

The New Madrid seismic zone of the southeast Missouri Bootheel region released several of the most powerful recent (geologically speaking) earthquakes in North America in late 1811 to early 1812. Three to five of these earthquakes have been estimated to be 7.5 to 8 magnitude earthquakes using the magnitude scales most quoted today (Hoffman, 2002). It is still an active fault system, which is being studied extensively. Although research has been conducted in earthquake prediction no one really knows when the next quake of that magnitude might occur. If there is a repeat of the temblor, there could be serious infrastructure damage which would possibly include: breakage of water and wastewater system piping, petroleum product pipeline damage, altered aquifers, disrupted barge traffic, well damage, road and bridge damage, electricity outages and contamination releases.

Water supply systems could be completely disrupted. Distribution lines and wells could be broken and leaking. The electricity might go out for a long period of time, thus rendering the treatment plants and pumps required to run the system inoperable. Similar things could happen to wastewater systems.

In the event of a large earthquake, aquifers could be seriously altered. It is possible due to the liquefaction potential of the Bootheel region that upper aquifers and the wells located in them might be damaged or destroyed. Although some disturbance of deeper aquifer systems (including karst) would result in water level changes and muddy water the long-term problems would be minimal.

A recent example of this was shown by the 7.9 magnitude earthquake that occurred on November 3, 2002 in a remote area in central Alaska. "Numerous wells have developed muddy or cloudy water. Large distant earthquakes can affect water levels in wells and can cause sediments in the rock and soil to be shaken and suspended in well water. Reports and records document these same phenomena caused by the Good Friday earthquake, a 9.2 magnitude event, that took place in Alaska in 1964. In 1964, the Geological Survey and Resource Assessment Division's groundwater level-monitoring network had several wells where the water level fluctuated significantly. The same thing has happened as a result of November 3, 2002 Alaskan earthquake. Geologists examined data from the groundwater level monitoring network and found significant changes in water level in at least 21 of the 70 wells that are in the network. The effected wells are located in 19 different counties, primarily in southern Missouri" (Hoffman, 2002).

Mississippi River navigation would at least be temporarily halted. There might be bridge collapses, making it impossible for barges to move past them. The course of the river might be altered, and the navigation channel filled in with sediment. Ports along the river might have their infrastructure severely damaged, rendering them inoperable. These potential changes could also make the river less suitable for recreation and wildlife habitat.

There are numerous opportunities for waterways to become contaminated due to accidental spillage from tank trucks, potential pipeline ruptures, mine tailings dam failures, landfill liner ruptures to name a few.

Sources:

Hoffman, David, Geologist III, Geological Survey and Resources Assessment Division, Missouri Department of Natural Resources, personal communication, November, 2002.

Aging Infrastructure of Public Water Supply Systems

Problem:

The basic equipment, structures and installations public water suppliers use to provide services can become less efficient or break down with age. Also, with increasing water demand some systems can no longer supply the needed water. It is difficult for many communities to find the money to adequately update their systems. Since much of the population of southern Missouri is served by public water supplies, any problems associated with aging water supply infrastructure need to be addressed.

Discussion:

The National Water-Use Information Program of the USGS estimated in 2000 that 61 percent and 66 percent of the population of southwestern and southeastern Missouri, respectively, was served by public water supplies. While the ages of municipal water supply systems and public water supply districts in southwestern Missouri range between 7 and 102 years, 64 percent of them are between 7 and 30 years old, 24 percent of them are between 31 and 50 years old, and 12 percent of them are 51 years old or more. For southeastern Missouri, the range is 10-102 years and 36 percent of them are between 10 and 30 years old, 19 percent of them are between 31 and 50 years old, and 45 percent of them are 51 years old or more.

The problems caused by aging water supply infrastructures are many. Aging water lines made of materials inferior to those allowed by current technology become fractured and begin to leak. Leakage, also called “transmission loss”, reduces system efficiency and can have a negative impact on the system’s revenue generation. This, in turn, may make it more difficult for the water supply system to finance much needed improvements in the future. A more common problem is rupture of these old water lines, which means that customers are without water until it is fixed, and there can be significant disturbance above-ground since workers have to tear up the

surface (often a road) to get to the pipes (Ryser, 2001).

Aging water supply infrastructures may also impact water quality. Outward leaking pipes also can leak inward if there is a sudden loss of pressure, allowing the system to become contaminated. In addition, service connections may have lead joints, which may leach lead into drinking water. Accumulations of lead and prolonged exposure to even very small amounts of lead can result in serious health effects. Older systems may also have “dead-end” lines in which water may become stagnant and undrinkable. Some rural water districts laid water lines with an older form of PVC piping, which in some cases may leach vinyl chloride (a known human carcinogen) into the water (Timmons, 2001).

Quite often, lines and facilities that were adequate when they were first constructed, are undersized when it comes to present service requirements. With age, systems may no longer be able to convey the amount of water that system users need. Present household, industrial and public uses (such as firefighting and drought response) may be limited. Without viable alternatives, future development may also be restricted as potential users are discouraged from locating their facilities in a service region unable to support their needs.

Sources:

Ryser, E., Manager of Systems Engineering Division, Kansas City Water Department, personal communication, February, 2001.

Timmons, T., Environmental Specialist IV, Water Protection and Soil Conservation Division, Missouri Department of Natural Resources, personal communication, February, 2001.

True Cost of Water

Problem:

The real costs associated with having clean water for all uses are often not directly paid for,

neither by the consumer, entities that may pollute water quality, or entities that produce water.

Discussion:

What is the real cost of clean water? The answer to this question is complicated for the costs are often dissipated throughout society. Some of the costs are relatively easy to quantify, such as the physical infrastructure to deliver treated water. There are costs that did not exist several years ago, such as those related to protection from terrorists and new regulations requiring treatment or testing for additional potential contaminants. Quantifying the financial cost of harmful effects on wildlife is difficult, especially if there is no apparent affect on game species.

Missouri is a riparian water law state, wherein there is no charge for taking water from its source in the environment, but we pay for treatment and distribution. However, the latter are often not fully paid for directly by the consumer, but subsidized through both state and federal grants. Supply lines need periodic replacement, which is a very expensive process (see topic on aging infrastructure). The American Society of Civil Engineers estimates that Missouri's infrastructure needs over the next 20 years are \$1.9 billion and \$3.2 billion, respectively, for drinking water and wastewater (ASCE, 2001).

There have been documented declines in the groundwater table in parts of McDonald, Greene, and Jasper Counties due to over-pumping (Brookshire, 2002). These lowered water tables can cause local residents' wells problems. This is an example of the cost being transferred from the entity causing the problem (cost externalization) to society whereas individual well-owners must pay a relatively high price to have their wells redeveloped, or pay for costly litigation to try to prove harm done.

In areas where water resources can be over-used, water is often not priced to reflect the importance of conservation. Money can be made by selling water since raw water can be produced free of charge, if water supply entities have the existing infrastructure to produce, treat and distribute the water.

The Total Maximum Daily Loads (TMDLs) program, which is part of the Clean Water Act, sets up criteria to determine the maximum pollutant load a water body can assimilate without becoming impaired. This load maybe divided up, or allocated, to all existing sources of the pollutant, which includes point and nonpoint sources. The goal is to use existing regulations to address point source concerns and promote voluntary actions on the part of nonpoint sources through the provision of funding for the installation of best management practices (2002 Missouri Department of Natural Resources). The cost associated with the established TMDL limits must be added into the cost of cleaning up the water for consumption.

Sources:

ASCE, 2001: www.asce.org/reportcard/index.cfm?reaction=states&state

Brookshire, C., Groundwater Hydrologist, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, May, 2002.

Missouri Department of Natural Resource, Geological Survey and Resource Assessment Division, 2002, **2002 Missouri Water Resources Law - Annual Report**, Water Resources Report Number 71.

Inefficient Water Use

Problem:

Water is a precious and often abundant natural resource with many uses. However, due to its apparent abundance it is used in ways that are not always efficient.

Discussion:

Water is essential to life. We often think it is unlimited, in part because we pay so little for

delivered water, which can lead to our wasting it. Water waste becomes a problem felt most strongly during times of drought, but there are other times as well when it is felt (i.e. the gradual growth of overall use by an increasing population such that it exceeds the supply in a region).

During times of drought, the need for water is felt more strongly. In part, this is because there is less of it and people are encouraged to conserve water so that a supply will last for everybody. It is exacerbated because drought impacts usually occur most during the time of year when water is needed most. Heat (plus drought) often makes people crave water more (for swimming, drinking, etc.).

Water supplies can be taxed even during times of abundant rainfall. Water use increases for two reasons: 1) increasing population and 2) per capita consumption tends to increase over time (USGS, 2002). Developing more water supplies is often expensive, and the amount of water available from a new reservoir is significantly more expensive than the amount of water saved via conservation practices (Gleick, 2000).

As water supplies become stressed many problems can occur. If a source runs out, it may need to be replaced, usually at a very high cost. If the source is from a reservoir, the quality may go down dramatically as the reservoir falls. This is due to water at the bottom often being turbid (muddy). If the source is from wells, the groundwater table may drop (see related topic), which can make wells go dry or make them produce less water, resulting in need to redevelop the well at great cost. Dropping groundwater tables can also cause subsidence in the surface of the land, causing all types of structural problems (although the geology of southern Missouri does not lend itself to subsidence). If the supply is from a stream, living organisms may have problems (i.e. low dissolved oxygen, habitat loss, etc.) because they may be considered less important than humans need for water.

Water waste takes on many forms. North Americans use many appliances that consume more water than the same appliance in other parts of the world. For example, your average European washing machine and dishwasher use considerably less water than models in the states. The way people landscape around buildings affects the amount of water they use.

High quality groundwater can be found throughout most of the region (there are a few areas of contaminated groundwater, and some areas with naturally-occurring high salinity groundwater that is unsuitable for drinking). The groundwater is an excellent source of drinking water since it is generally low in contaminants and does not need heavy treatment before use. However, population changes and increasing industrial uses have placed a burden on the resource, which is currently being mined in some areas ("mining" of groundwater refers to the process of extracting it at rates faster than it can be replenished).

Thermoelectric plants use lots of water, and some of them are considered "single-pass" users, (which means that fresh water is used once before being released into the environment). This water could easily be reused for many purposes.

Sources:

Gleick, P. H., 2000, ***The changing water paradigm: a look at twenty-first century water resources development***, *Water International*, Vol. 25, Number 1, PP127-138, March, 2000.

USGS, 2002; <http://water.usgs.gov/watuse>

Lack of Water Rights Laws

Problem:

The lack of statutory laws that delineate how much water a user is entitled to take from a source can be an impediment to the long term economic development and use of surface and groundwater resources of Missouri.

Discussion:

Missouri is a riparian water rights state. The laws guiding individuals and municipalities relative to water withdrawal and use are almost entirely court-made law (known as case law), rather than legislated (known as statutory) law.

Under the law, each riparian landowner has the same water rights.

The right of a riparian landowner to take water from a watercourse or an aquifer not only is recognized in law, but also is protected by law. But the guiding principle of riparian water rights law today is that the landowner may withdraw a reasonable quantity of water for personal benefit. The quantity withdrawn may not be so much that it adversely affects another riparian water user utilizing water from the same source. This allows the water user a great amount of freedom to utilize the surface water and groundwater located on and under their property.

Following case law, if the actions of one riparian adversely affect another riparian (perceived to be withdrawal of an unreasonable quantity or other adverse action), it is up to those parties to work out an amicable solution. Failing that, the plaintiff must bring suit in a court of law to enforce water quantity rights and seek legal relief and even reparation. The state government is not normally a party to such disputes in riparian water rights states.

A comprehensive case law review may not provide much guidance to someone who wants to withdraw large quantities of water. Statutory law does not address the question of quantity of water that can be withdrawn for use by riparian landowners.

Missouri courts which have addressed water quantity issues have fairly consistently held that water withdrawal and use questions involving quantity would be resolved on a case-by-case basis, with the courts as the determiners of what is reasonable.

This being the case, no riparian landowner can be completely sure of exactly how much water they are entitled to withdraw and what beneficial uses are recognized (by the court), to avoid the potential liability of "using too much water." In times of plentiful supply, the quantity of water that an individual may withdraw and use may not be the same as during times of drought. There is no guarantee of the quantity of water that a riparian can withdraw and use, and this can be a distinct disincentive to the development of long-term large quantity water uses. Farmers, businesses, and even municipalities can be reluctant to invest in the equipment needed to develop a water system if there is

any doubt that in the future they might not be able to legally take the quantity of water they need in order to continue operation. If a change in water law is contemplated this needs to be addressed so that farmers, businesses and municipalities have assurances in these areas, and so that future investments in the equipment necessary to supply their needs would be protected by statutory law and not subject to judicial law.

Under riparian water rights law, landowners have the right to use the water that is beside or below their lands, but they do not own it. Water in Missouri, like the air we breathe, is recognized in Missouri courts as a non-commodity, or a "free good," to which riparian landowners are entitled.

Hydrologically, southern Missouri is generally blessed with large quantities of good-to-excellent quality water. There are exceptions, such as the St. Francis Mountains area (where the groundwater is not available in large quantities), and the Osage Plains area (where the groundwater is highly mineralized). Nearly the entire region has an annual average rainfall of 42 inches or more. Parts of southeastern Missouri receive an annual average rainfall of 51 inches or more. Nevertheless, droughts do occur, and in the water-soaked year of 1993, the Bootheel part of Missouri suffered from a lack of rainfall.

While water is a "free good," only those who have the financial means can fully develop the supply sources. This general economic disincentive of water source development translates into a restricted general economic development condition.

Also, when there is a drought, the environmental needs of Missouri usually are not placed above drinking water concerns. Without legislation to provide guidance, fish and wildlife water needs may remain unprotected, and the question of how much water may be removed from a given source will remain unresolved.

Sources:

Gaffney, R.M., and Hays, C.R., 2000, Water Resources Report Number 51, **A summary of Missouri water laws**, Missouri State Water Plan Series Volume VII, Missouri

Department of Natural Resources, Division of Geology and Land Survey, 292 p.

Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, 2002, **Topics in water use: northwestern Missouri**, Missouri State Water Plan Series - Phase 2, Water Resources Report Number 61.

Agricultural Water Use

Improper Land Application of Poultry Litter

Problem:

Nutrient overloading of watercourses resulting from land application of poultry litter, in excess of agronomic rates, leads to eutrophication of waterbodies and degradation of groundwater. This is a potential health hazard as well as a water quality problem for aquatic organisms. The nutrient of particular interest here is phosphorus.

Discussion:

The focus of attention in this topic is a sub-region of ten counties in the southwestern corner of Missouri. This sub-region is a supplier of both agricultural products and recreation for Missouri and surrounding states. Some products are shipped across the entire United States and exported to other countries. Recreational developments in the area attract visitors from Missouri, across the United States, and other countries. High quality water is the key factor contributing to the success of these industries, and must be sustained in order to keep them both economically viable. (See also the topic, "The Condition of Water Can Affect Tourism.") The lakes of the sub-region are special attractions for the recreation and tourism industries that annually bring in over a billion dollars of revenue. Table Rock Lake is of particular note as an attraction (Young, 2001).

While poultry raising is common in Missouri, the poultry industries are concentrated in the ten counties of southwestern Missouri. In this area, enough chicken is raised to meet the needs of nearly all Missouri consumers, and enough turkey is raised to meet all the needs of Missouri consumers, plus many in nearby states (Young, 2001). Within this sub-region, four Missouri counties (Barry, Lawrence, McDonald, and Newton) raise most of the birds.

The poultry industries began vertically integrating in the 1950s, a process nearly completed by the end of the 1960s. Today, poultry production is extremely efficient financially, and very concentrated, geographically (northwestern Arkansas also is involved). One result has been that the market price of chicken meat has declined. Chicken has gone from a meat so expensive that it was consumed only on special occasions in the 1930s and 1940s, to a meat that is consumed almost daily in one form or another because it can be produced and marketed efficiently (Young, 2001).

The poultry raising farms, including concentrated animal feeding operations (CAFOs), have animal waste materials (manure), and ground cover materials (such as sawdust or wood shavings), that together constitute "litter," which must be disposed of properly. Poultry litter rightly is considered a fertilizer resource, and is not just "thrown away." The common management procedure is applying the litter to hay fields, pastures, and cropland. One challenge is that litter must be disposed of all year long, and not just during the growing season. Another challenge is that it must be applied at agronomic rates (the rates at which growing plants may take up the nutrients). Excess nutrients either soak into the top layer of soil, or run off into watercourses with stormwater. In addition to the nutrients, poultry litter has microbes that help the soil, and sometimes have other elements that hurt the soil. One such element is arsenic, approved by the U.S. Food and Drug Administration, used as an anti-coccidial (the coccids are a class of protozoan internal parasites of animals) (R. Foster, 2002).

In determining agronomic rates, agriculture professionals consider nitrogen as the critical nutrient. But poultry litter also is rich in phosphorus. Some within the industry are looking

at changing to consideration of phosphorus as the critical nutrient. Feed corn contains phosphorus, but in addition, a mineral supplement (containing calcium and phosphorus) is provided growing birds to assure good skeletal growth, as well as egg production in laying birds. Egg-laying birds require a ratio of about 12 parts calcium to 1 part phosphorus, whereas birds raised for their meat require a ratio of about 2 parts calcium to 1 part phosphorus (R. Foster, 2002).

Another, related, problem is the availability of phosphorus, itself. The U.S. is an exporter of phosphorus fertilizer, but reserves of high quality domestic phosphorus are dwindling, and it is predicted that most of our future phosphorus needs will be met by Southeast Asian and North African mines.

Dead birds are not part of "poultry litter." On the other hand, dead birds commonly are successfully composted on the farms, rather than burned or buried. Compost is not a regulated product, and does not have to meet quality standards.

The opportunity exists for value-added processing of poultry litter in some manner that would allow easier handling, shipping, and marketing, so that the fertilizer needs of those who raise grain for feeding operations could be met. Perhaps pelletizing the litter, packaging it in paper sacks, trucking it to market locations, and selling it as fertilizer would help move the litter away from those farms where it is not needed (a surplus exists beyond agronomic rates) to where there is a need. This is mentioned not as a solution to the problem, but to indicate that studies are currently underway to determine how best to make use of the manure resource safely and avoid the problems.

Until recently, scientists believed that phosphorus usually bound itself to soil particles, and moved primarily via erosion. Lately, it has been shown that phosphorus can move in relatively high concentrations in solution with runoff water when the soil levels become saturated. If poultry litter from southwestern Missouri were used at agronomic rates on other cropland in Missouri, there would be enough to supply three quarters of the state with fertilizer (Young, 2001).

In the Missouri Department of Natural Resources, the Environmental Assistance Office (EAO) now is working on a grant in southwest-

ern Missouri from the Environmental Protection Agency (EPA) under the terms of the Clean Water Act, Section 319, called the Elk River Poultry Litter Project. The Elk River also flows into Oklahoma, which has established stringent water quality standards. Phosphorus is the major identified problem in this grant project because it is a persistent nutrient. The goal of this project is to demonstrate the economic feasibility of composting poultry litter.

Poultry litter will decompose eventually, but composting hastens the process, resulting in a value-added product that improves both the fertility and the tilth of the soil. Composted poultry litter would be a commodity with market value (J. Foster, 2002).

Addressing the problem of too much phosphorus, land-applied more heavily than agronomic rates, will help to solve three problems. One is the disposal of poultry litter, another is water pollution, and the third is the conservation of the mineral phosphorus.

Sources:

Foster, Jerry, Missouri Department of Natural Resources, Outreach and Assistance Center, Environmental Assistance Center, presentation to the Missouri Water Quality Coordinating Committee, August 20, 2002.

Foster, Rose, Missouri Department of Agriculture, personal communication, October 29, 2002.

Young, Robert E., *et al.*, 2001, **Positive Approaches to Phosphorus Balancing in Southwest Missouri**, Food and Agricultural Policy Research Institute (FAPRI), University of Missouri, College of Agriculture, Food and Natural Resources.

Fish Farming

Problem:

Commercial aquaculture is a water intensive agricultural use that can have problematic side effects.

Discussion:

Commercial fish farming is increasing in Missouri and especially in the southeastern area of the state. Aquaculture chiefly involves species used for human consumption (food fish), but can include baitfish, ornamental fish, sport and game fish, crustaceans, and other plants and animals adapted for aquaculture. Catfish is the predominant food fish that is aqua-farmed. Of the 49 aquaculture farms identified in the 1998 Missouri agriculture census 44 are listed as raising food fish (fish for human consumption). In 1998 these 49 farms reported over \$5 million in sales, with food fish generating over \$3.7 million of that overall total. Ponds comprised the main method used for aquaculture (90 percent) with flow through raceways and tanks second (8 percent) and cages third (2 percent) (Missouri Agricultural Statistics Service, 2002). Missouri has a diverse aquaculture industry and many individual aquaculture businesses raise and sell a variety of products (Missouri Aquaculture Directory, 2002).

Raising fish for sale requires fish, a holding area, adequate quantities of water, fish food, and sometimes water and fish treatments or chemicals. Each of these places a quantity demand on the available water and can impact water quality and biological diversity downstream from the aquaculture farm.

Rearing ponds that utilize continuously active outlets can cause nutrient loading of waters downstream when bio-solids leave the confines of the pond. This can include uneaten food pellets and waste products directly from the concentrated numbers of fish. Rearing pond water conditioning regimens that are sometimes placed in the ponds to stimulate food chain organisms include horse or sheep manure, straw and alfalfa. These too, depending upon the situation, can cause downstream nutrient overloading. Water treatment chemicals are sometimes added to rearing ponds, as are bactericides and fungicides that are used to treat the confined fish. These substances can also move downstream and cause unintended consequences. Rearing ponds are sometimes flushed to remove excessive sediment or waste that has accumulated. When a rearing pond undergoes repair

to its gates or water control mechanisms, or to deepen or enlarge the capacity, the pond is often drained. If that rearing pond is connected to a stream then all these activities cause whatever is in the pond to be flushed out, into the downstream outlet, and into the environment.

The quantities of diverted water used in aquaculture applications can be small or can be relatively large. The aquaculture rearing ponds can utilize a short-term simple diversion, a longer-term diversion and retention system, or a passive instream method. Whatever the system, there is an active demand for adequate quantities of water. In times of water shortage, quantities that would have otherwise been left for other uses are utilized, increasing the overall water demand and thereby increasing the competition for the water that is available.

An unintended side consequence of aquaculture, in southeast Missouri, may be an increase in the otter population. Wild otters find a bonanza when they come across a pond full of farm raised fish. Otters are especially attracted to aquaculture ponds due to the relatively large number of fish in a confined space. Left unchecked this can lead to population increases of otters that feed on the farmed fish until that stock is exhausted or moved. The otters are then left to prey intensively on wild fish in surrounding water bodies. The Missouri Department of Conservation is studying the impacts otters may be having on small stream fish populations. Presently otters may be being blamed for declines in small stream fish stocks that are being impacted by drought. A factor that clouds the issue is that of increased susceptibility of fish to otter predation in streams which drought has reduced to a series of isolated pools resulting in reduced chances for fish to escape predation (Buchanan, 2003).

Sources:

Buchanan, Al, Missouri Department of Conservation, personal communication, March 10, 2003.

Missouri Agricultural Statistics Service, 2002
Missouri farm facts, 1998 census of aquaculture, www.agebb.missouri.edu/mass/farmfact/aqua.htm

Missouri Department of Agriculture, Missouri Aquaculture Association, and University Outreach & Extension, 2002, **Missouri aquaculture directory**.

Industrial Water Use

Effects of Metallic Mineral Mining

Problem:

Metallic mineral mining and exploration drilling in southern Missouri can be a water quality and quantity problem if proper safeguards are not followed.

Discussion:

Extensive mining in both southeastern and southwestern Missouri, particularly for metallic minerals (lead, zinc, iron, copper and silver) has occurred for several centuries. Presently, most of the country's lead supply comes from Missouri, with active mining occurring around Viburnum, Iron County. The metallic mineral mines, processing facilities, and exploration holes have caused pollution of surface water and groundwater, and could cause dewatering of an aquifer in a localized area.

When ore is processed, it is smelted to extract the desired mineral. The remaining waste rock is placed in huge piles or 'tailings ponds'. This waste rock contains trace amounts of metals and acids that can leach runoff into surface waters and/or leach into the groundwater if proper precautions are not taken. Sometimes, the tailings are placed behind earthen dams. Strong earthquakes may destabilize tailing ponds, triggering a release of the contaminated mining waste.

The impacts of metallic mineral mining have been widespread in the old "tri-state mining district" of southwest Missouri. This is an area that was mined from the mid 1800s to the mid 1900s. The approximately 100 years of mining activity has resulted in many problems.

Mining practices during this period of time did not take environmental protection into account resulting in land and water contamination.

Several problems can occur from unplugged exploratory drill holes. First of all, any unplugged drill hole can allow surface contamination into the groundwater. Another problem that can be indicative of some deep exploratory drill holes in southeast Missouri is that these holes can penetrate several aquifers. When this happens mixing of aquifers can occur usually resulting in the upper aquifer draining into the lower aquifer. Not only is there a potential for surface derived contaminants to be allowed to enter the lower aquifers but also dewatering of the shallow aquifers may result. This happened near Bixby, Iron County, when the casing for a ventilation shaft in a mine split and the upper aquifer drained into the ventilation shaft lowering the water table so that domestic wells ran out of water. The shaft was repaired and the mine that was responsible for the accident drilled new wells for the affected residents. There are thousands of unplugged, unknown mineral exploration test wells that can be a hazard for humans on the surface (who might fall in), as well as act as a conduit for pollution to enter an aquifer.

Industrial Pollution

Problem:

There are numerous pipelines, carrying petroleum, liquefied natural gas, propane, and other products, crossing the Mississippi River and passing through southeastern Missouri, subject to possible leaks. Closed city dumps and active sanitary landfills have the potential to pollute groundwater. Siting of sanitary landfills is difficult in the 46-county southern Missouri region because of seismic, karst, and groundwater issues. Various hazardous wastes are generated within the region, but there is no hazardous waste landfill in southern Missouri. Mine tailings ponds, often containing heavy metals, are unstable and could leak or give way as a result of a large earthquake.

Discussion:

Various kinds of petroleum products, refined in Texas and other nearby states, are transported by pressurized pipelines northeastward toward Chicago and other eastern markets. In the recent past, there have been pipeline breaks and spills of petroleum products in other Missouri locations such as the Chariton River and Gasconade River, which are not in this region. However, nowhere in Missouri is there a greater concentration of pipelines crossing the Mississippi River than in southeastern Missouri.

Because of the few numbers and locations of shut-off valves, and the potential for seismic events (the "New Madrid Earthquake Zone") or vandalism (terrorism) to cause a leak or a catastrophic break in a pipeline, the potential for loss of product and pollution of water bodies and groundwater is very great. Pipelines are regulated by the Missouri Public Service Commission.

Contaminants of various kinds, leaching from closed city dumps, have the potential to pollute community water supplies. Locations of closed city dumps are known only to those who remember where they used to be, or who come across one by accident. There is no state inventory of closed city dumps, and dumps, *per se*, are illegal. There are regional solid waste management districts, now, in Missouri. There are five active sanitary landfills in southern Missouri. Stringent regulations of what may or may not go into sanitary landfills, and the costs to support the regional system, contribute to illegal dumping along roadsides. There are not enough convenient places to put solid waste in the region. With only five active permitted sanitary landfills in the 46-county region, and the expense of having to design for seismic and karst hazards, there is a problem with people dumping solid waste in the woods or roadside ditches.

Hospitals generally have incinerators for biohazardous wastes, but other hazardous wastes have no place to go. There is no hazardous waste transfer or storage site in the region. Lone Star Cement kiln, Cape Girardeau, formerly burned hazardous wastes at high temperatures.

Mine tailings typically are stored behind earthen dams. Typically, these are located near

mined areas of the state. These tailings dams and the tailings stored behind them soon become saturated with water, hence are called tailings ponds. Seismic events could cause the earthen dams to give way and release the contents to downstream sites. Often, these dams contain large volumes of water, and the tailings contain various heavy metals, with the potential for environmental and safety concerns if they are breached.

The forest products industry is strong in southern Missouri. Among the products made in the region are dimension lumber, hardwood charcoal, shipping pallets, barrel staves, and various cedar and walnut items. Old sawdust piles can release a waterborne leachate that could contaminate downstream water supplies.

Sources:

Missouri Department of Natural Resources, Air and Land Protection Division, Solid Waste Management Program, www.dnr.mo.gov/alpd/swmp/sanopr.htm

Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, Geological Survey Program: Portion of Energy Resources Map showing pipeline areas, and portion of Earthquake Hazards Map of Missouri.

Building in Flood Plains**Problem:**

Significant areas of southern Missouri are flood hazard areas, those locations where flooding has occurred in the past and will occur again in the future. Investment in flood plain development is risky. Some cities and counties have regulations to guide development and allow the jurisdiction's participation in the National Flood Insurance Program. Nevertheless, flood plain development continues to occur in several different ways, with potential for socio-economic and environmental consequences.

Discussion:

Flood plains, by definition, occasionally flood. Often called “bottomlands,” flood plains generally are the low areas beside rivers and streams, and contain sediments that have been deposited by those rivers or streams over centuries. The deposits come from the particles carried by the water flowing in the streams during times of high flows and at high stages, and laid down on the bottomlands when the floods recede.

In Missouri, the muddy Missouri River carried soil from the Rocky Mountain states and high plains states to the Mississippi River, where, at their confluence, the flood plain lands are made of some of the most fertile soils in the world (Les Volmert, 1979).

In southeastern Missouri, the area spoken of as the “Bootheel” is a large flood plain. In pre-historic times, the counties of the Bootheel were a part of what is called the “Mississippi Embayment”. Much of the area is underlain by Quaternary-age alluvial sediments deposited by the ancestral and modern Mississippi and Ohio river systems on top of older Tertiary, Cretaceous and Paleozoic strata (Miller and Vandike, 1997).

When explorers and settlers first arrived in this area it was mostly swamplands. Since the turn of the century, the Bootheel area has been drained for agricultural development and leveed to prevent most floods. But, flooding can still occur in this area. The National Flood Insurance Program (NFIP), administered by the Federal Insurance Administration (FIA), an arm of the Federal Emergency Management Agency (FEMA), offers flood insurance for buildings and contents located in flood hazard areas. Customarily property owners’ and renters’ insurance policies do not cover flood losses, and one must ask for flood insurance coverage as an “extra,” like earthquake insurance. Rates are based on the elevation of the lowest floor of a structure, relative to the elevation of a base flood (BFE) (a once-in-a-hundred-years flood, or a one per cent chance flood), as determined by a Flood Insurance Study (FIS).

In order to avoid being required by a lender to purchase flood insurance, owners of flood plain property often opt to build structures up

on fill material. Building on a mound above the BFE reduces the risk of flood damage. However, the floodwaters that once might have overspread where that mound is, must go somewhere else. Filling flood plain lands force flood waters onto other properties that may not have been flooded.

In addition, altering the flooding of formerly flood plain lands changes the groundwater-surface water relationship, may jeopardize access to and from those lands, may increase flow velocities in the vicinity of the filling, and change the ecology of the territory that has been altered. Many local governments have had to purchase flood plain lands to restore them to their former grades, so that nearby roadways or other property will be safer, and so that future flood damages will be reduced.

Examples

In 1993, in the Upper Mississippi River Basin, which includes the Missouri River Basin, heavy summer rains caused unusually long-term flooding between April 1 and November 1, with three federal disaster declarations in Missouri because of extensive damages to real and personal property. In 1995, after repeat flooding of near-similar proportions, flood damages were much less. The reason was that in 1994, numerous buy-outs of property, with removal of structures, had eliminated many properties at risk.

In McDonald County, southwestern Missouri, a large discount store’s distribution center is being built in a flood plain (Buck, 2001). The lowest floor is above the base flood elevation at that location. The sewer lift station also was designed and installed above the 100-year flood elevation. McDonald County is participating in the NFIP, flood insurance is available, flood plain development regulations are in place, and lenders are aware of the hazards and the requirement to protect their loan portfolios. Some counties, however, are not participating in the NFIP and do not regulate flood plain development. Such regulations are separate from building codes, land use zoning, or master planning.

Floods can happen at any time of year. They are not limited to spring rainy seasons. Areas that are at risk of flooding can be mapped.

Levees are subject to failures, fill can be undermined, and flood insurance can be costly. Development can push floodwaters onto neighbors. The best uses of flood plains are uses that are compatible with occasional inundation, especially uses that take advantage of the richness of the bottomland soils.

Responsibility for governing development of flood plain lands rests with local levels of government, where they wish to exercise it, in the name of public safety, public health, and general welfare, as provided in the statutes of Missouri (Gaffney and Hays, 2000).

Sources:

Buck, Richard, Southwestern Missouri Regional Office, Missouri Department of Natural Resources, personal communication, October 24, 2002.

Gaffney, R.M., and Hays, C.R., 2000, Water Resources Report No. 51, **A summary of Missouri water laws**, State Water Plan Series Vol. VII, Missouri Department of Natural Resources, Division of Geology and Land Survey.

National Flood Insurance Program, Federal Insurance Administration, FEMA.

Schmutzlet, Dale, Missouri Department of Public Safety, State Emergency Management Agency.

Volmert, Les, St. Charles County (Mo.) District Conservationist, U.S.D.A., 1979.

Dam Operations

Problem:

The purpose, operations and management of dams, as well as their physical presence, impact the social, environmental and economic aspects not only of the immediate area but of the surrounding region.

Discussion:

Within the southwestern region of Missouri, there are four hydropower dams. Three of these are United States Army Corps of Engineers (USACE) managed and one is privately owned. The three USACE dams are Table Rock, Stockton and Pomme de Terre. Power Site Dam (Ozark Beach Power Plant) forms Lake Taneycomo and is managed by Empire District Electric Company. The largest lake in the region is Table Rock Lake, which can store 3,462,000 acre-feet (52,300 surface acres) of water. Table Rock Dam discharges into Lake Taneycomo, which is impounded by Powersite Dam. Table Rock Dam and Power Site Dam are on the White River. Stockton Dam can store 1,619,000 acre-feet (38,300 surface acres) of water in Stockton Lake and Pomme de Terre Dam can store 407,000 acre-feet (16,100 surface acres) of water in Pomme de Terre Lake (Davis, 2002).

The Geological Survey and Resource Assessment Division's (GSRAD) Dam and Reservoir Safety Program (D&RSP) lists 253 dams within the southwestern region and 18 of those are D&RSP regulated. The lakes created by these dams range in size from less than 1 acre up to 24,900 acres. Eleven of the 253 lakes are over 100 surface acres (Missouri Department of Natural Resources, 2002).

Within the southeastern region there are two major USACE dams, Clearwater and Wappapello. Wappapello Lake is the larger of the two, impounding a maximum of 625,000 acre-feet (23,100 surface acres) of water (USACE, 1946). Clearwater Dam can impound 413,700 acre-feet (10,400 surface acres) of water in Clearwater Lake (USACE, 1995). Wappapello is on the St. Francis River and Clearwater is on the Black River. Authorized for flood control and other purposes, Wappapello and Clearwater do not have hydroelectric power generating facilities.

The GSRAD D&RSP lists 637 dams within the southeastern region and 165 that are under their regulatory authority. The lakes created by these dams range in size from less than an acre to over 23,000 acres. Thirty-two of the 637 lakes are over 100 surface acres (Missouri Department of Natural Resources, 2002).

Benefits that dams provide can include water supply, aquatic habitat, recreational benefits, flood control, drought mitigation and hydropower generation. Compared to streams without dams, those with dams on average have greater water-volume continual flows, and generally have more stable year 'round flows. Such streams generally are not subject to the same frequency, duration and size of hydrologic events. Dams typically mitigate, to some degree, the peak of the hydrologic event (flood and drought). While it is not always the case, on rivers where dams are in place, they may provide continued downstream water flow, when otherwise the stream would go dry during extreme droughts. During flood events, dams typically retain the peak of the flood and release it over a longer time span, thereby lessening the downstream damage.

The primary or priority purpose of how the dam is managed and operated under varying water quantity conditions is also a water use issue. While some dams are installed and operated for the sole purpose of water supply, flood control, or recreation, generally the larger dams and their reservoirs are operated and managed for a variety of uses, resulting in these different use demands competing with one another – especially during time of extreme hydrologic water events. During extreme hydrologic and weather events, events can, at times, transpire in unique sequences with the resulting damages worse than if the dam were not there. Reservoirs may give a false sense of security for flood and drought protection and for a continued drinking water supply.

Power generation dams have different impacts than do water supply and flood water retention dams. Dams whose primary purpose is flood water retention may have very low water levels almost all the time, thereby making flood-water storage capacity available when needed. Once the flood has passed, the water is released from the reservoir in a controlled manner. Power generation dams, by their very nature, require certain amounts of water on an ongoing basis in order to generate electrical power. The height of the water column in the reservoir, behind the dam, determines not only how much water is available but also how efficiently power can be generated. Generally power generation dams

do not have as great a percentage of dedicated flood attenuation capacity as do dams intended purely for flood control, however power generation dams and reservoirs are generally much larger, so the actual volume of water is larger. While the greater volume of more stable water in a reservoir may be a benefit to plants, fish and wildlife, fluctuations in that water level at certain times may have a deleterious effect on those same plant and animal species.

Dams and reservoirs change the natural characteristics of the stream they impound, both above and below the dam. They definitely change water quantities and can change the chemical and temperature characteristics of the water, both above and below the dam. As a side effect of their construction they alter the natural environment, resulting in a generally more stable, but more unnatural, downstream environment. Obviously, upstream from the dam undergoes major environmental changes, as the once flowing stream becomes a lake. These changes directly impact the aquatic and terrestrial flora and fauna in both positive and negative ways.

Streams that are not dammed may have more natural flow regimes and as such are generally subjected to a greater variability in short term and long term average flows, due to the variability of precipitation, floods and droughts. Undammed streams typically have a more naturally evolved bio-community than do the artificially created and maintained environments of reservoirs and streams below the dam.

The competing uses for the available quantities of water both in the reservoir and released into the stream below the dam, is a water use issue. The more notable include water supply, recreation, and the support of aquatic and terrestrial species and the environments in which they live. Outflows of the dam can, under some situations, cause excessive channel cutting, bank sloughing and erosion, or even downstream flooding. Bottom releases from dams can have low dissolved oxygen under some situations. This can have a negative impact upon riverine aquatic species. Quantity of water can become an issue for the environmental, economic, and social oriented interests on both the lake and below the dam. This typically occurs during specific times of the year and is based upon the

water quantity demands, for example, of recreation or agriculture interests.

There is typically more economic and social activity centered on large lakes and reservoirs than free-flowing streams. However, there are notable exceptions to this, such as the Current, Jacks Fork, and Eleven Point Rivers, to name a few. Instream environmental differences, as previously noted, contrast sharply between reservoirs and free-flowing streams. Lakes and reservoirs not only change the floral and faunal content of the original stream but its very character as well. With construction of a dam, a shallow, fast flowing, warm water stream may be changed to a deep, cool water reservoir. Some plant and animal species adapted to survive in the stream are ill suited for life in the reservoir. Dams may also prevent the movement of aquatic wildlife. This is somewhat of a trade-off as the lake, however, may provide an expanded habitat for not only more but a greater variety of fish, animals and plants than the undammed stream. This is quite often seen as an opportunity, as many ponds, lakes and reservoirs created by dams are artificially stocked with gamefish species.

Reservoirs and rivers associated with dams generally provide greater recreational and economic opportunities. Greater recreational and economic opportunities equals more people, which means more pollution potential in lakes and streams including the use of motorized watercraft, which may release petroleum products into the stream and reservoir causing water pollution.

Sources:

Clearwater Lake Water Control Manual,
United States Army Corps of Engineers,
July 1995.

Davis, J., United States Army Corps of Engineers, Pomme de Terre Office, personal communication, July 25, 2002.

Missouri Department of Natural Resources,
August 1, 2002, **Missouri dam and reservoir inventory list**, Dam and Reservoir Safety Program, Geologic Survey and

Resource Assessment Division, Missouri
Department of Natural Resources.

Shannon, P, May 24, 2000, Missouri Department of Health and Senior Services, presentation on water quality findings in Lake of the Ozarks to the Bagnell Dam relicensing stakeholder workgroup.

U.S. Army Corps of Engineers, **The Master Plan Recreational Development Lake Wappapello**, Mississippi River Commission, 1946.

United States Army Corps of Engineers website:
www.swl.usace.army.mil

United States Army Corps of Engineers website:
www.nwk.usace.army.mil

Recreational Water Use

The Condition of Water Can Affect Tourism

Problem:

Situations where water quality is degraded or quantity is lacking can have a negative impact on tourism.

Discussion:

Many people travel to southern Missouri for water related recreation purposes. With parts of seven major reservoirs and many beautiful springs, canoeing streams, and caves, there is ample opportunity to enjoy water. For example, it is estimated that Taneycomo and Table Rock Lakes are in the top five lakes in the state in terms of fishing (Weithman, 1991). People enjoy water in various ways: boating, canoeing, jet skiing, water skiing, fishing, swimming, cruises on the lakes, etc. Many tourists are drawn to the region primarily for other purposes; but also participate in water recreation. The increased

tourism population may put a strain on local water supplies. A lot of money comes into this area as a result of tourism, which is an essential component to the region's economy. For example, Stone and Taney Counties both had tourism-related sales revenues of over 40 percent of their total sales (Kaylen and Langham, 2001).

If there are water quality problems to the regions waterways, tourists might stay away, for a variety of reasons. Areas might be declared off-limits for whole body contact because of elevated fecal coliform counts. This happened in the James River and Crane Creek (Kiner and Vitello, 1997). Although such a warning might last for a defined period, it can linger in people's minds thus affecting their decision to return.

Some water uses have adverse impacts on other water uses. For example, when the Corps of Engineers releases plenty of water out of Table Rock Lake, trout fishing is excellent on Lake Taneycomo. However, when they hold water back, Taneycomo's trout fishing is very poor. Although this may be good for the Corps' purposes, it may hurt others' uses of the same water. Several years ago there was a drought, which lead the Corps of Engineers to release less water out of Table Rock Lake into Lake Taneycomo. The latter's water, hurt the Rockaway Beach tourism industry. The Corps of Engineers is working to remediate the problem.

The health of the fish are an important indicator of water quality which can also effect local tourism. In the early 90's, there were health advisories on paddlefish in the James River due to chlordane contamination (Kiner and Vitello, 1997). Since many people come to the region for fishing, they may be reluctant to return if there are problems with either the fish or body of water. Lack of water could potentially hamper tourism as well. Severe restrictions on water use might make the beautiful landscaping and luxurious golf courses less attractive to tourists.

Sources:

Bayless, M. and Vitello, C., 1999, **White River Watershed Inventory and Assessment**, Missouri Department of Conservation.

Kaylen, M. and Langham, P., 2001, **Economic impact of Missouri's tourism and travel industry: January-December 2000**, MU Tourism and Development Center.

Kiner, L., and Vitello, C., 1997, **James River Watershed Inventory and Assessment**, Missouri Department of Conservation.

Weithman, A.S., 1991, **Recreational use and economic value of Missouri fisheries**, Missouri Department of Conservation.

Watershed Conservation and Land Use

Problem:

Commercial development in the Greater Branson Area of Stone and Taney Counties is changing the face of the land (topography) and the way stormwater runs off (hydrology).

Discussion:

While the geology of the greater Branson area is largely bedrock with a light soil (residuum) covering, adequate for trees and shrubs, the Ozark mountains of this area are fractured, and water is able to move quickly from the surface into the groundwater. Due to Branson's hilly terrain, it is necessary for commercial development to adapt. Theaters and motels, for example, are "terraced" onto the hillsides. Parking lots, which are numerous and covered with impervious paving allow more stormwater to be shunted to storm sewers and streams, altering the hydrology of those streams and the rivers to which they run, as well as groundwater recharge.

Commercial development is not limited to hotels, music halls, and stores. It includes the use of natural resources to supply the basic needs of construction (i.e. stone quarrying). While the watershed characteristics are being changed by the rapid development activities, there also is another consequence and that is the changing scenic characteristics.

There are many who know of the areas beautiful diversity. Those who have read the book, *The Shepherd of the Hills*, by Harold Bell Wright, an early 20th Century novel about life in Greater Branson in the late 19th Century, have become familiar with many landmarks of the area, such as the White River, Roark Creek, and Dewey Mountains. Those who visit Branson today, often visit Old Matt's Cabin and the viewing tower called Inspiration Point. The Ozark Mountains constitute one of the scenic attractions of Branson and visitors enjoy the forested mountainsides in all seasons. Highlights of the year are in April when the dogwoods are in bloom and in October when the fall colors are outstanding.

Population growth in the region presents varying points of view. Those who espouse "private property rights" proclaim that landowners have a right to do what they wish with their own property. Conversely, there is a point of view that recognizes that there is public interest in what is done, especially in a location of great scenic interest and attraction. It is the melding of the two that presents a challenge.

Two things are being disrupted in the Greater Branson Area, its watersheds and the scenic beauty of the area. Many Branson entrepreneurs make an effort to capitalize on the magnificent Ozark vistas and regional history and lore, including attractions like Silver Dollar City, but some do not. As a result, land use planning must be a vital consideration in future plans for this area.

Pathogenic Coliform Bacteria in Streams

Problem:

Streams can be rendered unsafe for whole body contact recreation by the presence of microbes.

Discussion:

There are numerous places (streams, lakes) in the southwest Missouri region where people

like to enjoy whole body contact recreation (i.e. swimming, water skiing, etc.). Unfortunately, many of these locations may suffer from contamination of human or animal origin. This contamination can enter waterways from leaking sewage pipes, sewer overflows, animal feedlots, wild animal waste, malfunctioning onsite sewage systems (septic or lagoon), etc.

Local health departments test at these recreation sites to see if there are indicators of fecal contamination (i.e. *E. coli*, total coliform), weekly in some instances, monthly in others. If a minimum threshold is surpassed further testing is instigated. In some cases, the location is declared off-limits.

An extensive study was undertaken in the summer of 2001 to analyze pollution in the James River basin (Weckenborg, 2001). Sampling took place during warm weather over the period of 1998-2001. Most of the sites exceeded the EPA-proposed single sample limit for *E. coli* (236 colonies) over 50 percent of the time, with one site in Wilson Creek having all of its samples greater than this limit. The sites with the fewest exceedences had the smallest populations living in their watersheds. The sources of the fecal pollution have not yet been clearly identified, other than those that occurred during the Springfield Wastewater Treatment Plant's sewage spill in the summer of 2000 (in the upper reaches of Wilson Creek).

Sources:

American Water Works Association (AWWA), 1990, ***Water quality and treatment: a handbook of community water supplies-4th ed.***

Weckenborg, S., 2001, Summer Intern, Southwest Regional Office, Missouri Department of Natural Resources, ***In-stream sample history for full body contact bathing beaches within the James River Basin as well as the Taneycomo and Bull Shoals Lakes Basin***, Missouri Department of Natural Resources internal publication.

National Scenic Rivers

Problem:

There are several potential environmental concerns to the National Scenic Rivers in south-eastern Missouri.

Discussion:

The Eleven-Point National Scenic River and the Ozark National Scenic Riverways (comprising the Jacks Fork and Current Rivers) draw tourists from around the country. This provides vital support to the local economy. However, numerous sources of pollution pose current and potential threats to the quality of the water, which can adversely impact tourism (see related topic “The condition of water can affect tourism”). These include: municipal sewage treatment plants, commercial logging, lead mining and an overload of waste from horses and humans during large gatherings.

The possibility of lead mining is another potential source of problems for these rivers (see related topic). Lead ore is known to exist in the region and there has been some exploratory drilling, with more proposed. The mining could dewater the aquifers or otherwise alter them. These aquifers sustain the flows of springs of the region, which in turn enable the rivers to remain navigable for small craft during drier times of the year. During drought conditions the spring flows allow these streams to flow as permanent streams, which is critical for survival of wildlife species. The mining could also bring various pollutants to the surface, which would be contained, in tailings ponds. These ponds can have catastrophic failures that could seriously pollute the rivers with heavy metals and acid. A study conducted in the Ozarks concluded that children had elevated blood lead levels due to the remnants of mining, posing serious health threats (Murgueytio *et al.*, 1998).

Commercial logging can cause other problems. Should clearcutting (one form of harvesting logs) consume greater acreage, it can have a significant change on the hydrology (increasing peak flows, and decreasing base flows) of the rivers. It can also lead to greater sedimentation

of the streams, thereby decreasing fish habitat and hurting the tourism industry.

There also may be negative impacts of large gatherings of people and horses in the region. The shod horses can be rough on streamside trails, causing greater erosion. Additionally, they add undesirable nutrients and fecal pollution. The large numbers of visitors (with their horses) could be a problem if their waste is not managed properly. These are possible reasons (along with municipal effluent) for the fecal contamination of the Jacks Fork River (Davis and Richards, 2002).

Sources:

Davis, J. and Richards, J., 2002, ***Assessment of microbiological contamination of the Jacks Fork within the Ozark National Scenic Riverways, Missouri-phase I***, found at: <http://missouri.usgs.gov/wtrqual/images/jsfork4.pdf>

Murgueytio, A., Evans, R.G., Sterling, D., Clardy, S., Shadel, B., and Clements, B., 1998, ***The relationship between lead mining and blood lead levels in children***, *Archives of Environmental Health*, 53:414-423.

USGS, 2002: <http://mo.water.usgs.gov/mining/dyetracing.htm>

Problems Associated with Recreational Uses

Problem:

Recreational use of waters and lands adjacent to waterbodies by large numbers of people and over long periods of time can cause direct and indirect water problems.

Discussion:

The Ozark region of southern Missouri is a recreational destination for both Missourians and

out-of-state visitors. The regions are dotted with numerous lakes and rivers - Table Rock, Taneycomo, Clearwater, Wappapello, and Bull Shoals Lakes and Current, White, Jacks Fork, Eleven Point, and James Rivers, to name a few, that attract millions of people annually to water-related recreational activities. In 1999, estimated tourism expenditures in the southwest and southeast regions amounted to over \$2 billion, with over \$1.6 billion of that generated in the Springfield and Branson area alone. For southern Missouri, tourism and recreational expenditures ranges from a high of over 11 percent of the region's economy in certain areas to a low of 2 percent. Approximately 58,000 southwest and southeast Missourians are directly and indirectly employed in tourism and recreational industries (Highfill, 2002). In southern Missouri, water related recreation is big business.

Across southern Missouri canoeing, floating, swimming, wading, boating, fishing, and jet boating are common. Unfortunately, wherever people congregate, pollution may become a problem. The water pollution can be caused by leaking, spilled or improperly disposed engine fluids from watercraft, trucks, cars, motorcycles, and ATV's. The pollutants can be a result of improper human waste disposal or sanitation facilities. It can come from pets or improperly disposed of trash. The pollutant can be in the form of chemical (petroleum products, insect repellents, cosmetics, detergents, and pharmaceuticals) or biological (bacteria from feces or spoiled and rotting food-stuffs).

Much of the Ozark National Scenic Riverway (ONSR) area is underlain by karst topography of soluble limestone and dolomite, which gives rise to losing and gaining streams, sinkholes, caves, and springs. There are over 300 identified caves within the ONSR boundary area. It contains the world's largest collection of First Magnitude springs. The Current and Jacks Fork Rivers attract approximately 1.5 million recreational visitors each year, most to canoe, float, swim and fish. Pollution incidents, both acute and chronic, have occurred within ONSR. Possible sources include recreationally contributed wastes from both humans and horses (NPS, 2002). Trail

rides, rodeos, and horseback riding is especially common in Shannon County in the Eminence area. Horse derived waste in streams in the Ozark National Scenic Rivers has been confirmed by sampling analysis and is a concern. Horses that are ridden across or in streams dislodge and stir up sediment, which can be problematic for aquatic animals, aesthetics, boaters, and fishermen.

Studies by the US Geological Survey, National Park Service, Missouri Department of Natural Resources, and others indicate that heavy recreational use is causing adverse impacts on water quality to the point that water-quality standards for whole-body-contact recreation is sometimes exceeded. The intense recreational use of the Jacks Fork River has caused problems associated with greater competition for the use of a finite resource, sanitation facility issues, and the proliferation of litter. In 1998 a 5-mile stretch of the Jacks Fork was added to the Missouri Department of Natural Resources' Section 303(d) impaired waters listing. The identified pollutants contributing to the listing included fecal coliform bacteria from humans and other warm-blooded animals. Potential sources include cross-country horseback riding, campground toilets, canoers, boaters and float tubers (USGS, 2001).

The widespread use of recreational all terrain vehicles (ATV's) can cause terrestrial and aquatic damage by wearing trails and ruts on hillsides and streambanks and destroying terrestrial vegetation which leads to erosion, disturbing streambeds, and leaking gasoline and oil. Ozark streams are characterized by gravel and sand streambeds. Excessive sedimentation can adversely impact aquatic species that require high quality clear water. Excessive sedimentation also makes the stream less attractive as recreation sites. The West Fork of the Black River has had particularly heavy use by ATV users (Missouri Department of Natural Resources, 2001). Except under certain conditions, driving an ATV in a stream is forbidden by state statute RSMo 304.013.

Because of its karst topography, losing streams in the southwest and southeast regions compound the surface water quality problems with ground water quality issues.

Surface water pollutants can end up underground – in a sinkhole, cave or aquifer. The potential for damage to sensitive cave ecosystems and drinking water supplies is a concern.

While most issues are associated with water quality and water quantity, too many people trying to use the same body of water for different uses, can also become a problem. Increasing popularity and use of an area has caused problems associated with greater competition for the use of a finite resource (USGS, 2001). As an example, too many canoers and jet boaters trying to use the same water body at the same place can lead to arguments or accidents, just the opposite of what people seek from recreation.

Sources:

Highfill, Kevin, 2002, ***The economic impacts of tourism in Missouri***, Missouri Department of Economic Development.

Missouri Department of Conservation, 2002, ***Watersheds inventories and assessments***, MDC Website: www.conserva.state.mo.us/fish/watershed/mdc40.htm

Missouri Department of Natural Resources, September 23, 1998, Section 303(d) Waters list.

National Park Service (NPS), 2002, Ozark National Scenic Riverways Website: www.nps.gov/ozar

Missouri Department of Natural Resources, Southeast Regional Office, State Water Plan joint meeting, December 11, 2001, meeting minutes.

United State Geological Survey (USGS), March 2001, ***Assessment of microbiological contamination of the Jacks Fork within the Ozark National Scenic Riverways, Missouri—phase I***, USGS Fact Sheet 026ñ01.

United State Geological Survey, 2002, ***National Water-Quality Assessment Program—Ozark Plateaus surface-***

water study, http://mo.water.usgs.gov/fact_sheets/surfwat.asp

Environmental Water Use

Population Dispersion

Problem:

Population dispersion adds to a number of water-related problems. These include increased instream sedimentation, flooding and drought impacts, watercourse pollution, water demand, spending on infrastructure, and human health and property damage risks.

Discussion:

The population in southwestern Missouri has both increased and spread out into rural areas. Christian, Taney and Stone Counties grew by over 50 percent during the 1990s, with Barry, Dallas, Hickory, Laclede, McDonald, Polk, and Webster Counties growing by 20 to 30 percent. The entire region's population grew by 25 percent (150,000) during the past decade. This spread of suburbia often termed urban sprawl, leads to a host of water problems.

During construction, ground is often left bare and heavy rains can cause the soil to erode and wash into streams, causing turbidity and sedimentation. This in turn can cause problems for aquatic species. Contractors can install sedimentation mitigation measures, such as plastic fences to keep soil on site. However, often they are not effective and they are only mandated for sites over 5 acres (to be changed to 1 acre effective in early, 2002) (Madras, 2001).

The increased impervious area (roofs and pavement) from the new development in watersheds can exacerbate stream problems related to both flooding and drought. These hard surfaces don't allow for infiltration of the water into the soil and subsequently the groundwater. Instead, this water is shed quickly to the stormwater system. Many local government

subdivision regulations require that stormwater be shunted as quickly as possible into the nearest watercourse in order to prevent local flooding. Since more water is added to the system in less time, a higher flood peak with a shorter lag between rainfall and flooding occurs. This flooding also causes greater streambank destabilization because of the increased frequency of higher peak flows. There are porous paving systems, which (when combined with the right kind of soils) can increase infiltration.

Since many of the impervious surfaces get very hot from sunshine, the water that runs off them is heated and can increase the overall temperature of nearby streams, lakes and ponds.

Some of the water shunted to the stormwater system would normally infiltrate to the groundwater, which in turn seeps back to the surface at streams (termed a stream's base flow). This is especially important during drought, as this base flow is what keeps enough water flowing in streams to sustain aquatic life. This stormwater also carries an increased pollution load into local waterways (Smith, 2001). Oil on pavement, road salts, floatables and lawn-care chemicals are among the pollutants. An increase in pollution can render the treating of water for drinking more costly. This pollution can also kill or seriously impair the survival of aquatic biota.

With this increase in populations comes a greater demand on drinking water systems. Increased demand comes not only from a rise in population, but also a rise in per capita demand. This situation can stress the resource. This increased demand can necessitate expanding treatment plants which might increase costs that would be spread throughout the entire locality, raising everybody's property taxes.

The negative effects of urban sprawl on water resources are widespread, from pollution to flooding, to impacting fish habitat. These effects are not easily categorized and cross many disciplines which makes addressing the issues more difficult because of their diverse nature.

Sources:

Drew, John and Chen, Sherry, 1997, Water Resources Report Number 49, **Hydrologic**

extremes in Missouri: flood and drought, Missouri State Water Plan Series Volume V, Missouri Department of Natural Resources, Division of Geology and Land Survey, 104 p.

Gaffney, Richard M., Chief Watershed Planner, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, May, 2001, personal communication.

Madras, John, Planning Section Chief, Water Protection and Soil Conservation Division, Missouri Department of Natural Resources, April, 2001, personal communication.

Smith, Andrew, June, 2001, "New Satellite Maps Provide Planners Improved Urban Sprawl Insight," www.gsfc.nasa.gov/gsfsc/earth/landsat/sprawl.htm

Stormwater Runoff

Problem:

Runoff from storms in urban areas causes many problems related to both the volume of water that goes into streams and its quality.

Discussion:

We plan our development in ways that will minimize stormwater damage to humans, infrastructure, and buildings. This is usually done with engineered infrastructure (i.e. gutters, storm drains, storm sewers, retention basins, etc.) rather than with low-impact designs (i.e. vegetated swales, porous paving, etc.). The engineered infrastructure moves water away quickly and efficiently so as to decrease ponding and localized flooding. Stormwater runoff in urban areas causes problems because of the changed flow volume and velocity, and because of the pollution that is added as it flows from the urban area. These problems include threats to public health, economic activity degradation, natural resource degradation, decreased aquatic community health, aesthetic decline and more.

The hydrology of the runoff's flow is drastically changed in urban areas. As an impervious area (i.e. roofs, roads, etc.) is added in development, more water runs off, since less can infiltrate the ground. In addition, this runoff is directed to receiving water bodies much quicker, since the flow is not slowed by vegetation. Both of these factors make for the stream to have a peak discharge that is higher and quicker than it would have been without development. In some places, this can be by a factor of 2 to 5 times the discharge for the same storm (USEPA, 1993; Schueler, 1992). With a higher discharge comes a greater velocity, thereby causing more kinetic energy available for causing channel and associated infrastructure changes. When surface imperviousness reaches 25 percent of total area, flood magnitudes that once were one hundred year events can become five year frequency events (Klein, 1979). Unfortunately, stormwater solutions (i.e. getting the water out of an area as quickly as possible to decrease flooding and associated problems) for an area often cause increased flooding for a downstream area.

In addition to increased flooding, this changed hydrology has other deleterious impacts. The high flows also can cause aquatic habitat loss from increased scouring. Streambanks can become destabilized, which causes increased erosion and subsequent channel widening, which can "steal" somebody's property. Silt carried in from construction projects, and increased streambank erosion can be a problem for aquatic plants because they might not get the sunlight needed for photosynthesis due to turbid water. This sediment can also clog fishes' gills, causing infection, asphyxiation, and other diseases. Once water slows down, it deposits the sediment. This can ruin aquatic habitat by filling spaces between rocks where fish lay their eggs and invertebrates hide. In addition, sediment fills reservoirs and lakes, which can have serious economic impacts, such as the high cost of dredging.

The decrease of water infiltration due to impervious surfaces causes problems as well. Since vegetated areas and their associated microorganisms, plus the soil, act as filters and bioremediators of pollution, urbanization decreases this functioning. Aquifers are not re-

plenished, which can negatively affect drinking water supplies because they may not be able to pump enough water with existing wells. These aquifers also supply water to the river (termed "base flow"); this is critical for sustaining flows during times of low or no precipitation. These flows are important for maintaining aquatic habitat, and can help to dilute pollution from wastewater treatment facilities.

Stormwater runoff carries a wide assortment of pollutants into streams. Trash washed into receiving waters is an aesthetic problem and can cause problems for aquatic species. Since many surfaces in an urban environment get hotter than a vegetated area, stormwater runoff can heat up significantly as it runs over these surfaces. This, combined with fewer trees shading streams in many urban areas, make for increased temperatures of streams, which decreases dissolved oxygen levels and can harm aquatic species that need a certain temperature range for survival. Oils and pesticides transmitted to streams are often toxic and can be endocrine disrupters (see related topic). These can be harmful to both aquatic species and humans who may consume the water downstream. Many of these types of contamination can be a problem for commercial and recreational fishing. Fecal coliform can adversely impact human recreation (swimming, boating, fishing) downstream. For example, it was determined that fecal indicator bacteria densities were several orders of magnitude higher from stormwater than the state limit in the Springfield area (Richards and Johnson, 2002). This same study also determined that contaminants from pesticides and petroleum sources were added in such quantity, via stormwater, so as to possibly cause genotoxicity in aquatic fauna.

Sources:

Klein, R.D., 1979, **Urbanization and stream quality impairment**, *Water Resources Bulletin*, Volume 15, Number 4, August 1979, p. 955.

Richards, J.M. and Johnson, B.T., 2002, **Water quality, selected chemical characteristics, and toxicity of base flow and urban stormwater in the Pearson**

Creek and Wilsons Creek Basins, Greene County, Missouri, August 1999 to August 2000, USGS Water-Resources Investigations Report 02-4124.

Schueler, T.R., 1992, **Mitigating the adverse impacts of urbanization on streams: a comprehensive strategy for local governments**, in Metropolitan Council of Governments and the Anacostia Restoration Team, Watershed Restoration SourceBook, a collection of papers presented at the Conference *Restoring Our Home River: Water Quality and Habitat in the Anacostia*, November 6 and 7, 1991, College Park, Maryland, pp. 21-31.

U.S. Environmental Protection Agency (USEPA), 1993, Handbook: **Urban runoff pollution prevention and control planning**, EPA 625-R-93/004, September 1993, p. 3.

Introduction of New Chemicals Into Use

Problem:

There are many chemicals currently in use which end up in the water. The effects of many of these are unknown, and it is unclear what harm they may cause to public health and the environment.

Discussion:

Only a fraction of the 80,000 chemicals registered with the EPA have undergone testing to see if they have impacts on human health and the environment (Weiss and Landigran, 2000). Only 23 percent of the 3,000 chemicals produced or imported at over 1 million pounds per year have been tested to determine their potential for human developmental damage (Weiss and Landigran, 2000). With so little known, there could be serious problems with many of the chemicals, problems that do not show their effect for 20 to 40+ years, or we do not understand the problems because scientists

may not be looking in the right way. In addition, there are instances where a company has covered up their knowledge about the negative impacts of a chemical they produce (Grunwald, 2002). Holding them accountable is both expensive, time-consuming and doesn't diminish the physical afflictions from the chemical.

Chemicals can end up in the water in a number of ways, primarily: in runoff from agriculture, urban settings and industrial processes; from point sources such as industrial releases and municipal wastewater treatment plants effluent; and seeping into groundwater via infiltration into the soil; and atmospheric deposition (via dust and rainfall).

There is a group of chemicals, known as persistent organic pollutants (POPs), that are known to: bioconcentrate (they become more concentrated as they wind their way up the food chain. They can also spread around the globe (a 1988 study found one, hexachlorobenzene, in penguins, over 1000 miles from its source) and be toxic with a long lifespan (i.e. they don't degrade quickly). An international POPs treaty banning the production and use of the 12 worst chemicals has been signed, but not yet ratified. Most of these chemicals are banned in the USA (i.e. PCB, DDT, etc.). However, many of them are still being found in cells of US citizens, partly because they persist since the time when they were legal here, partly because they can travel around the globe (via food and weather) from places where their use is accepted. These are clear examples of the introduction of new chemicals into use where we didn't know the ramifications of the action. The cost to clean up superfund sites often runs in the \$100s of millions, with one site in this state (Weldon Springs) costing over \$1 billion to remediate. There has not been a clear accounting of the costs from litigation, health care, lost economic productivity, decreased tourism dollars, etc., but it is sure to be significant. Harder to quantify, yet of great importance, is the loss of human life, health problems, and environmental damage.

The toxicological testing paradigm has its weaknesses, as well. The convention has been to look for carcinogenicity, and not explore other types of potential problems, such as endocrine disruption (see related topic). In terms of carcinogenic effects, acceptable limits in drinking

water are established (no adverse effect level, NOAEL). However, recent studies show adverse effects to the endocrine systems at levels 0.0001 that of the NOAEL, as well as a non-linear effects relationship (i.e. significant problems at high and low doses, and none at medium doses) (Gupta, 2000; Sheehan *et al.*, 1999; vom Saal *et al.*, 1997). It has been shown that a group of endocrine disrupters, phthalates, may potentially cause birth defects in humans (Blount *et al.*, 2000). This is another example of a chemical being introduced into use without a good understanding of its negative effects.

Some suggest that we follow the precautionary principle of the POPs treaty, which states that when scientific knowledge about the impact of a chemical is not fully known, but there is enough information to raise legitimate concerns, then regulations should be introduced to protect public health. As then-Governor of New Jersey Christine Todd Whitman said, "We must acknowledge that uncertainty is inherent in managing natural resources, recognize it is usually easier to prevent environmental damage than to repair it later, and shift the burden of proof away from those advocating protection toward those proposing an action that may be harmful" (Appell, 2001).

Sources:

Appell, David, 2001, **The new uncertainty principle**, *Scientific American*, January, 2001.

Blount, B.C., Silva, M.J., Caudill, S.P., Needham, L.L., Pirkle, J.L., Sampson, E.J., Lucier, G.W., Jackson, R.J., Brock, J.W., 2000, **Levels of seven urinary phthalate metabolites in a human reference population**, *Environmental Health Perspectives* 108:979-982.

Gupta, Chanda, 2000, **Reproductive malformation of the male offspring following maternal exposure to estrogenic chemicals**, *Proceedings of the Society for Experimental Biology and Medicine* 224:61-68.

Grunwald, Michael, January 1, 2002, **Monsanto hid decades of pollution**, *Washington Post*, January 1, 2002, Tuesday www.washingtonpost.com/wp-dyn/articles/A46648-2001Dec31.html

Longnecker, M.P., Klebanoff, M.A., Zhou, H., Brock, J.W., 2001, **Association between maternal serum concentration of the DDT metabolite DDE and preterm and small-for-gestational-age babies at birth**, *The Lancet* 358: 110-114.

Sheehan, D.M., Willingham, E., Gaylor, D., Bergeron J.M., and Crews, D., 1999, **No threshold dose for estradiol-induced sex reversal of turtle embryos: how little is too much?**, *Environmental Health Perspectives* 107:155-159.

Sheehan, D.M. and vom Saal, F.S., 1997, **Low dose effects of hormones: a challenge for risk assessment**, *Risk Policy Report* 4(9) 31-39.

vom Saal, F.S., Nagel, S.C., Palanza, P., Boechler, M., Parmigiani S., and Welshons, W., 1995, **Estrogenic pesticides: binding relative to estradiol in MCF-7 cells and effects of exposure during fetal life on subsequent territorial behavior in male mice**, *Toxicology Letters* 77:343-350.

vom Saal, F.S., Timms, B.G., M.M. Montano, M.M., Palanza, P., Thayer, K.A., Nagel, S.C., Dhar, M.D., Ganjam, V.K., Parmigiani, S., Welshons, W., 1997, **Prostate enlargement in mice due to fetal exposure to low doses of estradiol or diethylstilbestrol and opposite effects at high doses**, *Proceedings of the National Academy of Sciences*, 94:2056-2061.

Weiss, B. and Landrigan, P.J., 2000, **The developing brain and the environment: an introduction**, *Environmental Health Perspectives* Volume 107, Supplement 3, June, 2000.

Endocrine Disrupters and Water Pollution

Problem:

Low-level chronic contamination of water-courses with toxic substances have effects on aquatic organisms that are still being studied. Pharmaceuticals and Personal Care Products (PPCPs) that include endocrine disrupter chemicals are among the environmental pollutants that are being studied by the Water Resources Division of the United States Geological Survey, the U.S. Environmental Protection Agency, and others.

Discussion:

The Toxic Substances Hydrology Program of the Water Resources Division, USGS, currently is performing investigations into what they term, "Emerging Water Quality Issues." They call this a National Reconnaissance of Emerging Contaminants.

To quote from one of the 2002 USGS information bulletins,

"Recent decades have brought increasing concerns for potential contamination of water resources that could result inadvertently during production, use and disposal of the numerous chemicals offering improvements in industry, agriculture, medical treatment, and even common household conveniences.

Increasing knowledge of the environmental occurrence or toxicological behavior of contaminants has resulted in increased concern for potential adverse environmental and human health effects. For many contaminants, public health experts have incomplete understandings of their toxicological significance (particularly effects of long-term exposures at low-levels).

The need to understand the processes controlling contaminant transport and fate in the environment, and the lack of knowledge of the significance of long-term exposures has increased the need to study environmental occurrence down to trace levels. Furthermore, the possibility that environ-

mental contaminants may interact synergistically or antagonistically has increased the need to define the complex mixtures of chemicals that are found in our waters."

Of particular concern are endocrine disrupters, those synthetic organic and other chemicals that mimic animal hormones, and interact with cells to prevent normal activity. Other concerns relate to antibiotic resistance in the environment. The initial focus of the national reconnaissance is on 95 specific chemicals, sampled at low concentrations. Among these are sulfonamide and tetracycline antimicrobials in both groundwater and surface water.

In an effort to gain further information and understanding of the endocrine disruption problem, the USGS co-sponsored the *2nd International Conference on Pharmaceuticals and Endocrine Disrupting Chemicals in Water*, held in Minneapolis, Minnesota, in October, 2001, and will be co-sponsoring the American Water Resources Association specialty conference, *Agricultural Hydrology and Water Quality*, in Kansas City, Missouri, in May, 2003.

What is meant by PPCPs is a very diverse assortment of prescription and over-the-counter drugs, fragrances, cosmetics, sun-screens, insect repellants, nutrition products, and other products used or consumed for personal health or cosmetic reasons. The overall concern is that no sewage treatment plants are engineered for PPCP removal. The risks to aquatic wildlife and human beings from continual life-long exposure or consumption of minute quantities in water are not known, but are being studied. Major issues are pathogen resistance to antibiotics, and disruption of endocrine systems by natural and synthetic gender steroids. There may also be unknown consequences. Most research to date has been done in Europe, with North American studies more recently.

The EPA's involvement has been through the National Exposure Research Laboratory (NERL) and the Office of Research and Development (ORD). The ORD has assumed the leadership role in EPA research in this field. Also involved are the American Chemical Society (ACS) and the German Institute for Water Research. One of the significant publications in this field is the periodical, *Environmental Health Perspectives*.

Threats

The threats posed by endocrine disrupters and other chemicals to the natural environment include the development of resistance among naturally occurring pathogens to antibiotic compounds that cure or stave off infectious diseases, and the presence of estrogenic and androgenic hormones in water that can feminize or masculinize aquatic wildlife. Other chemicals being studied include calcium channel blockers and efflux pump inhibitors. The ultimate disposition of these chemicals in the environment is water, from streams to leachate from landfills and groundwater.

The presence of female hormones in rivers in Great Britain has been affecting male fish in those rivers. Detected for several years, scientists now are pinpointing the cause. Professor Alan Pickering of the Natural Environmental Research Council (United Kingdom) suggests that estrogen in the urine of pregnant women and those taking either estrogen therapy or birth control pills could be creating the “gender-bending” pollution.

The professor noted that the hormones could be reactivated by processes used in modern sewage treatment, which use bacteria to break down wastes. In some rivers, such as the Aire in Yorkshire, 100 per cent of male fish showed female characteristics. Because not all fish need to reproduce to maintain a species, fish numbers have not yet shown a decline, but the professor said that a question relates to predators, such as otters, which might also be affected. The amounts of hormones needed to alter the gender of a fish are so small that even with modern scientific testing, they are hard to detect, he said (Chapman, 2000).

Occurrence, persistence, and trends are being studied and monitored. Most PPCPs in the environment occur at concentrations well below therapeutic doses. Therefore, looking for acute reactions is different from looking for the less-obvious chronic effects of exposure. The effects of low concentrations on multiple generations of aquatic species may be subtle but significant, and research is continuing. For example, exposure to the insecticide diazinon is known to affect signaling pathways, leading to

alteration of homing behavior (implications relate to predation, feeding, and mating).

It may be that one of the outcomes of the research now being done will relate to “proper disposal of unused or expired” drugs, such as birth control pills. Often, patients are advised to flush unwanted pills down the toilet. But sewage treatment plants are not designed to remove such chemicals and they end up in natural watercourses. Another outcome might relate to imprudent prescribing and over-prescribing of certain drugs, and even of over-dispensing of drugs via the Internet or by mail. Still another may relate to the design and operation of wastewater treatment plants, which presently are unable to remove endocrine disrupters and many other chemicals from the waste stream.

Here is an opportunity to educate physicians, pharmacists, manufacturers and consumers to the Precautionary Principal. The Precautionary Principle is when the burden of proof is shifted to the makers of PPCPs and other chemicals to prove that they are safe to use, and safe to dispose of. An example of a product that did a lot of environmental harm (while being beneficial) includes the insecticide, DDT (banned in the U.S.A., but still being used overseas). DDT accumulates in the bodies of fish, birds and animals in the food web, and causes thin eggshells in birds such as American bald eagles.

Sources:

Chapman, James, September 7, 2000, ***How pollution is making river fish change sex***, *London Daily Mail*.

www.epa.gov/nerlesd1/chemistry/pharma/index.htm October 17, 2002.

toxics.usgs.gov/regional/emc.html October 17, 2002.

www.epa.gov/nerlesd1/chemistry/pharma/faq.htm October, 2002.

Coal

Problem:

Using coal to generate electricity causes a number of potential water pollutants to be released in a variety of ways.

Discussion:

Coal combustion is the largest generator of electricity not only in Missouri, but in the United States, as well. This combustion releases a variety of pollutants. However, pollutant-release is not confined to the time of combustion, but also occurs at various steps in the entire process of using coal. Many pollutants, such as mercury, are released into the atmosphere during combustion, only to be deposited later, downwind. Eighty percent of mercury contamination has been attributed to coal combustion. Others remain in the combustion ash and are combined with those from the scrubbers (which take pollutants out of the exhaust), to be placed in a landfill, which in turn can leach out via stormwater if the landfill is not constructed properly.

During coal firing, a lot of the pollutants are emitted in the smoke stream. Some of these are trapped by scrubbers, which are used to minimize the release of certain pollutants (e.g. sulfur dioxide, SO₂, a major component forming acid rain) into the atmosphere.

Coal waste (the combination of ash and scrubber remains) can be a significant source of pollutants in the region if not handled appropriately. Although scrubbers extract pollutants from the exhaust, it does not mean that these no longer exist, it just means that they are transferred from one medium (air) to another (solid or liquid, depending on the situation).

There are three coal-fired power plants in southwestern Missouri: two in Greene County, one in Jasper County. However, water pollution from coal (via aerial deposition and stormwater runoff) is not confined to downwind of power plants in Missouri since it can travel long distances in the atmosphere.

Landfills and Dumps

Problem:

Landfills and dumps (illegal landfills) are sources of pollutants for nearby water bodies.

Discussion:

Our society produces huge quantities of waste (solid and hazardous) that we usually choose to dispose of in landfills and dumps. Estimates of the quantity of landfilled material in 1999 in the USA range from 165 million tons (USEPA, 2002) to 267 million tons (BioCycle, 2002). Missouri places approximately 5 million tons of waste in landfills annually. This material contains a large variety of substances, with many potential pollutants included, such as organic chemicals, oil and heavy metals, all of which can mix with water.

The current design method for sanitary landfills is termed “dry tomb”. The basic idea is to have impermeable barriers above and below the refuse so that no water gets to it, or out of it, to spread pollution. The lower liner is sloped so that leachate will flow to a collection point, where it can be pumped for treatment. However, even the USEPA, which promulgated the design standards, admits that these liners will eventually fail to prevent leachate from passing through them, although it may be delayed by several decades (USEPA, 1988a; USEPA, 1988b). This is problematic in that many of the components in a landfill that can pollute will not degrade over a few decades, or even a few centuries. For example, it is estimated that these contaminants could pollute for at least 1,000 years (Belevi and Baccini, 1989). Thus, it appears inevitable that groundwater will be polluted from some of these sites (Lee and Jones-Lee, 1993). What is not known is when, with which pollutants, and how extensive it will be (all of these are site-specific). In addition, the monitoring regimes for detecting groundwater contamination from a landfill are often inadequate, detecting pollution only after widespread contamination (Lee and Jones-Lee, 1998).

Another source of pollution is from illegal dumps. In many rural locations, there is no gar-

bage pickup by a local government. People living in these areas have no convenient or inexpensive method for disposal of their waste. Therefore, some of them resort to throwing their trash in a convenient place, which may be in a corner of their backyard, or an absentee landowner's gully. This provides for direct leaching into watercourses and groundwater. Since this occurs in so many places, it is difficult to predict the extent and impact of this pollution. Often, there are car batteries with leaking acid, old refrigerators leaking toxic coolants, and various other contaminants. These dumps can be a particular problem in the southern region because they are often in a local sinkhole, which provides a direct conduit for the contaminant to enter the groundwater.

Sources:

Belevi, H. and Baccini, P., 1989, **Water and element fluxes from sanitary landfills**, *Sanitary Landfilling: Process, Technology and Environmental Impact*, Academic Press: San Diego, pp.391-397.

BioCycle, 2002: www.jgpress.com

Lee, G. F. and Jones-Lee, A., 1993, **Landfills and groundwater pollution issues: 'dry tomb' vs F/L wet-cell landfills**, Proc. Sardinia '93 IV International Landfill Symposium, Sardinia, Italy, pp. 1787- 1796, October.

Lee, G. F. and Jones-Lee, A., 1996, **Dry tomb landfills**, *MSW Management*, 6:82-89.

Lee, G.F. and Jones-Lee, A., 1998, **Assessing the potential of minimum subtitle D lined landfills to pollute: alternative landfilling approaches**, Report G. Fred Lee & Associates, El Macero, CA, March.

United States Environmental Protection Agency (USEPA), 1988a, **Solid waste disposal facility criteria: proposed rule**, Federal Register Volume 53, pp. 33314-33422, 40 CFR Parts 257 and 258, US EPA, Washington, D.C., August 30.

United States Environmental Protection Agency (USEPA), 1988b, **Criteria for municipal solid waste landfills**, US EPA Washington, D.C., July.

United States Environmental Protection Agency (USEPA), 2002: www.epa.gov/epaoswer/non-hw/muncpl/pubs/excsum99.pdf

Gravel Mining

Problem:

In-stream gravel mining can affect stream hydraulics and hydrology, and can damage aquatic flora and fauna, especially through habitat destruction.

Discussion:

Many southwest and southeast Missouri stream channels are a convenient source of gravel for construction projects, gravel road maintenance and other purposes. Most of the region's streams are Ozark-type gravel-bottom streams.

Unsound gravel removal from and adjacent to, stream channels can alter stream channel form, may increase sedimentation and turbidity, may aggravate flooding problems, and can have negative impacts at, below and above the removal location. Research in gravel bed streams of the United States and elsewhere has indicated that in-channel extraction of gravel destabilizes the bed and banks of stream systems. Flood plain gravel removal does not have the same hydraulic effects, as long as the stream bank remains intact. However, there is a clear danger of stream bank destruction in future flooding, causing hydraulic effects.

Extraction can cause aquatic habitats to be degraded and aquatic species to be reduced in number or eliminated (Roell, 1999). The southern Missouri region contains several federally listed species that have the potential to be negatively impacted by gravel removal.

Gravel removal is a common practice in many Ozark streams in the regions. Gravel is used for building construction and roads. It is

in high demand, especially because of the large and rapid population growth and related development the southwestern region is experiencing now. Gravel is taken directly from stream channels, often in large quantities. Stream gravel is an industrial natural resource. It is used in several ways. For example, gravel is used as an aggregate in Portland cement concrete and in bituminous concrete, as a porous fill material around drainage tile, as a backfill material in some kinds of on-site sewage disposal systems, as a fill material when laying water pipes, and as a surface material in unpaved roads and driveways. Stream gravel can be graded to size. In these regions, it usually is an attractive light tan color, and is popular for driveways. Gravel is a valuable economic commodity.

The most widespread effects of in-channel gravel mining on aquatic habitats are bed degradation and sedimentation. Several studies have documented the bed degradation that occurs during in-stream gravel mining. Two general forms of in-stream mining occur: pit excavation (trenching) and gravel bar skimming (scalping) (Kondolf, 1997). Bed degradation is manifested in two ways. First, excavation of gravel mining pits in the active channel causes a local lowering of the stream bed, creating a so-called "nickpoint" that locally increases channel slope and therefore flow energy. During high flows, nickpoints are a location of vertical bed erosion that gradually moves upstream in a process called headcutting (Bull and Scott, 1974; Kondolf, 1997) which mobilizes significant quantities of stream bed materials that are then transported downstream to refill the excavated area. Headcuts often move well upstream and into tributaries (Scott, 1973; Harvey and Schumm, 1987; Kondolf, 1997), in some locations as far as headwaters or until halted by non-erodible surfaces in the stream channel such as bedrock or man-made structures.

A form of mining-induced bed degradation occurs when gravel removal creates a local sediment deficit either at a bar-skimming site or an in-channel pit (Kondolf, 1997). A sediment deficit exists when there is not enough sediment being carried by the stream. Any stream has the ability to carry sediment, depending on factors such

as the availability of sediment, velocity of flow, volume of water in the stream and the temperature of the water. A skimming operation locally increases channel flow capacity and a pit operation locally increases flow depth; both operation types result in decreased flow energy, causing heavier sediment arriving from upstream to deposit at the mine site. As stream flow moves beyond the site and flow energies increase in response to the "normal" channel slope downstream, the amount of transported sediment leaving the site is now below the sediment carrying capacity of the flow. The water picks up more sediment from the stream reach below the mine site, furthering the bed degradation process (Kondolf, 1997). This degradation is also due to the flow energy increasing as it leaves the mine site.

Channel incision not only causes vertical instability in the channel bed, but also causes lateral instability, in the form of stream bank erosion, followed by channel widening (Heede and Rinne, 1990). Incision increases stream bank heights, which cause bank failure when the mechanical properties of the bank material cannot sustain the material weight. This instability increases the mobility of channel sediments and their transport downstream (Parker and Klingeman, 1982).

Diverse physical habitats of alluvial gravel streambeds provide resources for diverse communities of fish and other creatures. Pools below gravel removal sites tend to be longer and shallower than undisturbed areas, and riffles occur less frequently than would be expected. In most cases, channel widths also increase at and downstream of gravel removal sites. Different species of fish require unique spawning, rearing, and feeding areas, as do different species of macro invertebrates (Brown, 1992). Gravel mining can adversely affect diverse habits.

The extent of instream gravel mining is not well quantified. Although commercial gravel extraction operations need permits, noncommercial operations and county and local governments do not. It is estimated that approximately 75 percent of all operations are not permitted by the state (Femmer, 2002).

Sources:

- Brown, A., 1992, **Impacts of gravel mining on Ozark stream ecosystems**, Arkansas Game and Fish Commission.
- Bull, W.B., and Scott, K.M., 1974, **Impact of mining gravel from urban stream beds in the southwestern United States**, *Geology*, 2:171-174.
- Femmer, S., 2002, **Instream gravel mining and related issues in southern Missouri**, USGS Fact sheet: <http://mo.water.usgs.gov/factsheets/wtrqual/Gravel/fs012.02.pdf>
- Harvey, M.D., and Schumm, S.A., August, 1987, **Response of Dry Creek, California, to land use change, gravel mining and dam closure**, Pages 451-460 in *Erosion and Sedimentation in the Pacific Rim*, proceedings of the Corvallis symposium, International Association of Hydrological Sciences Publication 165.
- Heede, B.H., and Rinne, J.N., 1990, **Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research**, *North American Journal of Fisheries Management*, 10:249-268.
- Kondolf, G.M., 1997, **Hungry water: effects of dams and gravel mining on river channels**, *Environmental Management*, 21:533-551.
- Parker, G., and Klingeman, P.C., 1982, **On why gravel bed streams are paved** *Water Resources Research*, 18:1409-1423.
- Roell, M.J., June, 1999, **Gravel and sand extraction in Missouri stream systems: potential effects and proposed actions**, Missouri Department of Conservation.
- Scott, K.M., 1973, **Scour and fill in Tujunga Wash - a fanhead valley in urban southern California - 1969**, U.S. Geological Survey Professional Paper 732-B.

Deforestation**Problem:**

Harvesting of trees on a large scale can have negative effects on water quantity and water quality.

Discussion:

Much of the Ozark region in southern Missouri is covered with forests. Timber production supports the local economy by providing jobs for lumberjacks, haulers, saw-mill operators, etc. These jobs can continue to be maintained through sustainable harvesting, which ensures sustained productivity of forest ecosystems and maintains their health. However, when proper techniques are not followed, the hydrologic cycle can be altered, and aquatic habitat can be degraded.

When a forest is clearcut, most of the trees in an area are harvested or cut down and the hydrologic cycle is changed. Less water infiltrates the ground since it does not have the trees to intercept the rain and slow it down so that it has time to enter the soil. In addition, the soil surface becomes hard from a combination of the soil cover (decomposing leaves, downed limbs, etc.) washing away, and the underlying layer compacting from raindrop impact. This lowered infiltration decreases groundwater recharge, which in turn lowers the amount of baseflow and spring flow into streams. Since less water infiltrates, more runs off, and faster, which increases the volume of floodwaters' flow. This higher peak flow can increase stream bank destabilization. Higher flow velocity, combined with bank destabilization, can endanger bridges and other structures close to a stream's edge.

Clearcutting can also cause problems with water quality. During harvesting, often the act of dragging trees out and driving over the terrain leaves significant portions of soil vulnerable to erosion with moderate to heavy rainfall. This eroded soil enters a stream, becoming suspended sediment. This sediment can clog fish gills and cause other harm to aquatic species. When the sediment settles out, it fills inter-gravel spaces, thereby ruining spawning habitat. The quantity of soil eroded can be large, which is

problematic in the Ozark Hills because of their already thin soils, and the steep slopes that exacerbate erosion. This erosion decreases the long-term (i.e. measured in centuries) productive potential of an area. The lack of trees by a stream's side can also cause it to heat up, decreasing the amount of dissolved oxygen it can hold and causing other problems for temperature-sensitive aquatic species.

There are currently two large mills in the southeastern region (at Scott City and Mill Springs) that consume enormous amounts of wood. When running at full capacity, they use the equivalent of 20-30 acres clearcut per day. These mills turn the wood into chips to be transported for processing. Most of the land they get wood from is privately owned, although some of it is public. Although operation of these mills does not mean that best management practices are not followed during timber harvesting, it has been shown that they encourage poor harvesting (Guldin, 1999). A study conducted in the Ozarks indicates that uneven-age management of forest resources produces a larger amount of timber, and thus economic returns during a 25-year period than even-age management (clearcutting) (Iffrig *et al.*, 1999). This type of harvesting is also better for water quantity and quality, as well as wildlife habitat.

Economic and water quality contentions may be true although following silvicultural best management practices, clear cutting should have minimal impact on water quality. Some species of wildlife benefit more from clear-cutting, particularly a series of small clear cuts which produce a lot of "edge", than uneven-aged management (Buchanan, 2003).

Sources:

Buchanan, Al, Missouri Department of Conservation, personal communication, March 10, 2003.

Guldin, J., July, 1999, **Hardwood chip export mill harvests in Arkansas: good forestry or not?**, Presentation to Governor's Advisory Committee on Chip Mills.

Iffrig, G.F., Trammel, C.E., and Cunningham, T.C., March 4 and 5, 1999, **A case study for**

sustainable forest management in the Missouri Ozarks—45 years of single-tree selection harvests and an economic model for income production, Draft Paper Presented to The 1999 Environmental Sustainability and Public Policy Conference, Towards a Vision for Missouri's Private Forests.

Perlin, J., 1989, **A forest journey: the role of wood in the development of civilization**, W. W. Norton, Publisher, New York, New York.

Water and the Ability of our Plant Life to Help Keep it Clean

Problem:

Forests, savannahs, and prairies, which perform their functions of respiration, transpiration, and absorption, cleanse the air of wind-borne pollutants, including dust and chemicals, and cleanse the water of dissolved and silt-borne pollutants. While this is good for the air and water, the ability of our plant life to clean an ever increasing contaminant load may have negative consequences.

Discussion:

Forests are not plantations of trees. They are forest ecosystems that contain trees of many species in addition to shrubs, ferns, and other undergrowth, in biosynthesis with animal life of many genera. Savannahs are much more open than forests, being mostly grasslands, with occasional trees. Prairies are combinations of grasses, shrubs and occasional trees. The different combinations give each prairie landscape a character of its own.

When the human population was small (as in tribal times before the days of large settlements), the pollution or contamination component in air and water resources was small. (Air pollution can have a direct effect on water qual-

ity, therefore it is referred to in this problem statement and discussion.) The landscape could cleanse the air and water of all the customary problem components without difficulty. This is done in a complex biogeochemical process, in which organic and inorganic forms of nitrogen and other elements are processed by natural systems.

Large settlements of human beings, with characteristic industrial and commercial enterprises, created new and different chemicals, concentrated mine tailings, concentrated animal waste, and removed large expanses of vegetation which would have helped clean up the pollution.

The pollution that is not “cleaned up” by Missouri’s plant life either runs off and eventually ends up in the Gulf of Mexico or seeps into the ground. If it seeps into the ground the natural filtering action of soils and rock layers help to clean it up. But, due to the karst geology of much of southern Missouri some of the surface water infiltrates so fast or contains so much pollution that it carries with it its contaminant load into the subsurface groundwater of Missouri.

Unnaturally high levels of plant nutrients and other coastal pollution have caused so much damage that 44 percent of coastal waters now cannot fully support aquatic life, human activities such as fishing, or both. According to Robert Wayland, the EPA director of wetlands, oceans and watersheds, “The message for the public is ... not to take these valuable resources for granted” (Watson, 2002).

As reported in *USA Today*, “Wayland attributed the Gulf’s low standing in part to the vast acreage from which it collects water. More than 40 percent of the land mass of the continental USA discharges water to the Gulf,” he said. Among the observations were eutrophic conditions, sediment contaminants, and fish contamination with toxins. High levels of nutrients from farm, forest, and urban runoff, industry, and sewage treatment plants in the Midwestern States (including Missouri) have contributed to the pollution of the Gulf of Mexico. Coal-burning power plants in the Midwest are cited as contributing to acid rain in the eastern United States.

Missouri’s forests and waters are important resources, being damaged by the pressures of

today’s civilization. The more we know, the more we need to mitigate and remediate the problems we are discovering.

Sources:

Watson, Traci, “EPA gives coast waters generally low grades,” in *USA Today*, March 2002, reporting on the *National Coastal Condition Report*, Washington, D.C., 2002.

ScienceDaily Magazine, ©2002, at www.sciencedaily.com

Altered Watercourses in the Bootheel

Problem:

Over the past century, waterways in the Bootheel section of southeastern Missouri have been drastically altered, increasing the potential threat to humans and their property, and decreasing ecosystem functions.

Discussion:

The lowlands part of southeastern Missouri, known as the Bootheel, are both low in elevation and have very low slopes. Before European-Americans came to the area, it was primarily wetlands.

Since the early twentieth century, Missourians have drained the wetlands, and created a series of drainage ditches, all in order to make the land available for farming. This has been and is still the most productive agricultural land in the state. The rivers were straightened to increase their drainage efficiency as they carried water toward Arkansas and the Mississippi River.

During the period 1914-1928, several rivers of southeastern Missouri were cut off by the digging of a large drainage canal across the region by the Corps of Engineers (COE). This drainage canal is located just south of Cape Girardeau, and is crossed, today, by Interstate

Route 55, from which the traveler can get a good view of the size of the canal. The Castor and Whitewater Rivers are major rivers cut off by the digging of the drainage canal. They originate in the eastern Ozarks. What is left of the Castor River below the cut-off carries drainage water from the Bootheel only. Two other rivers, the Black and St. Francis, had dams built on them in the 1940s, thereby finishing the work of preventing too much water from entering the lowlands (Gideon, 2002).

The waterways of the bootheel system are really drainage ditches (straightened, leveed watercourses engineered to move water away as quickly as possible), as opposed to natural streams. Very little of the original flora and fauna is left, which could have been a draw for tourists (and still is in some of the state parks and conservation areas where parts of the original ecosystems remain intact). In addition, the ditches no longer perform the ecosystem services (cleansing the water, minimizing problems associated with stormwater runoff, etc.) that the natural streams and wetlands do. There are virtually no riparian corridors in the bootheel.

Another potential area of concern regards the Mississippi River floodplain, specifically the New Madrid Floodway. This area is designed to be a relief valve. When the river is at high flood stages, a front-line levee is designated to be destroyed (flooding a large area) to bring the river level down, thereby minimizing the flooding downstream in places like Memphis. The area to be flooded by this levee breach is rural and agricultural. The COE has easements to flood the entire area. However, this will not be popular with the local residents, who do not want their homes and farmland flooded. One day, there will be a flood large enough where such an action will be recommended (as occurred in 1937).

Concerning restoration of wildlife habitat, there is a program sponsored by MDC, NRCS and Ducks Unlimited to encourage farmers to flood their rice fields over the winter (NRCS, 2002). This is to provide over-wintering habitat for waterfowl, and to help cleanse water and provide more recharge. It is rather like restoring wetlands, for part of the year.

Sources:

Gideon, 2002, <http://gideon.k12.mo.us/town/river3.htm>

Natural Resource Conservation Service (NRCS), 2002, www.mo.nrcs.usda.gov/bootheel1.html

Governmental Agencies Coordination

Problem:

There are numerous government entities that deal with water-related issues. For a variety of reasons, they are often reactive rather than proactive concerning various issues. Each agency has its own mandates and viewpoints concerning water related issues which can on rare occasions create disagreement on how to address an issue.

Discussion:

Government agencies (federal, state, and local) deal with water related issues in many ways: permitting and regulation, research, monitoring, basic resource assessment, technical and financial assistance, planning, etc. They deal with many aspects of water from quality issues to quantity issues relating to the environment, drinking water, water safety, transportation on water, flooding control, drought mitigation to name a few. All of these different functional areas of government can create conflict if coordination and cooperation does not occur. Such problems are not specific to one agency, rather they can cross all levels of government.

Sometimes agencies are too busy reacting to problems, and therefore, do not have enough time to be proactive concerning potential problems. Problems are more expensive and difficult to take care of once they have occurred than if they had been prevented from happening in the first place. It is a bit of a catch-22: to be able to prevent such problems, they must

have the staff to complete the work, but are often understaffed and therefore are forced to play catch-up. A proactive approach requires foresight, planning, proper management, and good data. It may cost more up front, but the amount of money saved in the long run can be tremendous.

Another area where management of water might be enhanced concerns interagency and interstate cooperation. There are numerous instances of agencies working together to create something better than if one were undertaking it alone (i.e. the Stream Teams Program, which is a collaboration between Missouri Department of Natural Resources, Missouri Department of Conservation, and the Conservation

Federation of Missouri). However, there are times when effective working relationships are impaired. Sometimes this is due to lack of knowledge about what another entity is doing. Sometimes it is about someone defending their 'turf'. Sometimes there are external controls that inhibit cooperation, such as a lack of funding, or legal frameworks that impede positive interactions. It is the citizens of Missouri and the water resources that lose from such poor cooperation.

Also, "unfunded mandates" complicate the picture. When a governmental agency requires another one to implement a regulation without also allotting the funds necessary to do so, this is termed an unfunded mandate.



Water Use Opportunities and Regional Observations

In the process of creating this report, several “success stories” and opportunities in water use have been recognized as well. Although the goal of this series is to identify problems rather than offer solutions, some of these findings are described below. By taking note of successes (and opportunities for success), we recognize approaches that work, and can use them as stepping stones to problem resolution. Water use opportunities are presented in this section to stimulate further thought and discussion, without endorsement of feasibility or merit.

Long Range Studies

The value of long-range studies is becoming increasingly important as a tool to help in addressing water use issues defined in the State Water Plan. The basic need for scientifically derived data is essential to be able to make accurate decisions on water resource issues. The long-range aspect is essential to determine the nature of a specific problem. The ability to show trends and analyze these trends is also important to not only protect the water resource, but so no unnecessary regulation of the resource occurs.

An example of a long-range study that is reaping dividends is the departments groundwater monitoring network that has been collecting groundwater level data since the mid 1950s. This data shows which areas within the state have dropping water levels and which ones do not. This information is vital in addressing water quantity issues.

A newly begun long-range study focuses on monitoring shallow groundwater for four ag-

ricultural pesticides. This study began in early 2002 and is designed to provide data necessary to develop and implement effective pesticide management plans. This study, which is carried out by the departments Water Resources Program, focuses on the distribution and occurrence of atrazine, simazine, alachlor, and metolachlor, which are herbicides used extensively on corn and soybeans.

The study focuses on water yielding rocks near the surface, which are also sensitive to surface activities. The area of the study encompasses a portion of the Missouri River alluvium in central Missouri and the Missouri Bootheel region. These are the areas that meet the shallow aquifer requirement and have the above-mentioned pesticides applied to corn and soybean crops.

Data show that about 96 percent (43) of the samples did not contain any detectable concentrations of any of the pesticides analyzed for, including four pesticides that are not the focus of this project. The concentration of alachlor (.88 micrograms/liter) detected in one well was above the method detection limit (MDL) (.2 micrograms/liter) and practical quantitation limit (PQL) (.5 micrograms /liter) of the analytical method but was lower than the USEPA drinking water standard of 2 micrograms /liter. The concentration of metolachlor (1.86 micrograms/liter) detected in an additional well was also above the MDL (.2 micrograms /liter) and PQL (.5 micrograms /liter) of the analytical method but less than the USEPA drinking water standard of 70 micrograms/liter (Baumgartner, 2002).

Sources:

Baumgartner, Scotty, D., 2002, **Results of monitoring Missouri's shallow groundwater for four agricultural pesticides - Spring 2002**, Department of Natural Resources, Geological Survey and Resource Assessment Division.

Water Efficiency Makes Good Economic Sense

It is easy to take water for granted. Whenever we turn on the tap, water comes out - pure, clean, and drinkable. What most of us do not realize is that every drop of water that comes out of the tap has been carefully treated to remove impurities and make it safe for drinking (unless you have a private domestic water supply). Processing all that water is an expensive job. It is wise to use water efficiently in our homes and businesses.

The industrial, commercial and institutional sectors are key allies in helping municipalities save money. Reducing water consumption will reduce the need to build new water and wastewater treatment plants. Taxpayers could save themselves billions of dollars over the near future if excessive water usage is reduced. Water efficiency makes good business sense. Reducing water consumption is one option that businesses may not have considered to lower costs, become more efficient, and increase competitiveness.

Residential water use accounts for 47 percent of all water supplied to U.S. communities by public and private utilities. Increasing water efficiency in this important sector can preserve more water for the environment, reduce water supply, wastewater-treatment, and related costs for communities. There are many opportunities to use household water more efficiently without reducing services (RMI, 2002).

Water-saving techniques save money, reduce the amount of pollutants entering rivers, lakes, and streams, and protect aquatic ecosystems. Efficient water use reduces water and wastewater treatment costs and the amount of

energy used to treat, pump, and heat water. Conserving water also eases the burden on water resources during drought conditions. There are a wide variety of fixtures and appliances that help reduce water use. Installing high efficiency plumbing fixtures and appliances can help a typical family of four reduce indoor water use by one-third, save about \$95 per year on their water and sewer bill, and cut energy use by as much as six percent (USEPA, 2002).

The less water we use, or abuse, the less we degrade this precious resource and the less money we have to spend bringing our water resource back to an acceptable standard. To ensure that the water coming out of your taps is clean and of good quality, use water wisely today.

Sources:

United States Environmental Protection Agency (USEPA), 2002, **Water Conservation and Efficiency**, available online at www.epa.gov/owm/water-efficiency/sectwco.htm

Rocky Mountain Institute (RMI), 2002, **Household Water Efficiency**, available online at www.rmi.org/sitepages/pid123.php

Sustainable Groundwater Resources

Missouri's greatest groundwater resources lie in the southern part of Missouri. The groundwater is the least understood and almost always undervalued. For many cities and counties in Southern Missouri, incorporating conservation and increased efficiency in water management may be the most economically feasible way to meet their future needs. Postel concluded that only by managing water demand, rather than ceaselessly striving to meet it, is there hope for a truly secure and sustainable water future (Postel, 1986).

Groundwater in Missouri is mostly replenished, or recharged by precipitation. Shallow aquifers receive this recharge relatively quickly,

but deeper aquifers covered by hundreds of feet of strata are generally recharged much more slowly. Thus, water pumped from these deeper zones is not being replenished at the same rate as is it being withdrawn. Drawdown occurs as wells are pumped and the water level in the well bore lowers. However, drawdown is not limited to the well bore – it occurs in all directions from the pumping well and creates what is termed a cone of depression. Drawdown decreases as distance from the pumping well increases. However, as more wells are drilled, cones of depression often overlap and then the drawdown has a cumulative effect on water level. Domestic wells and smaller industrial or municipal wells will suffer the effects of a regional water level decline first, due to their shallower depths and smaller capacity pumps.

Most municipalities in Southern Missouri depend upon groundwater as a partial to full source of supply for their customers. Because it is generally more economical than purchasing water from another supply, commercial users of groundwater tap into the resource almost daily. Irrigation demands further stress the on the groundwater ‘pool’. And finally, domestic wells supply water to thousands of homes and small farms throughout the area. As more residential and commercial growth occurs in the southern part of Missouri, groundwater levels will continue to decline unless a sustainable water demand management approach has been adopted or other sources of water are pursued.

Water quality problems in the lower aquifer may begin to appear as upper aquifer groundwater, which is more easily contaminated, moves downward as a result of changes in hydraulic head caused by pumping. As more growth and development occur in the southern part of the state, groundwater resources are becoming impacted on a regional basis.

Developing new water supplies may not be the only opportunity that exists to meet the increasing water demand. There is a limitation to the traditional supply-side approach. The most accessible sources of water have now been developed, and deeper drilling is becoming increasingly expensive. The answer may lie in reducing the demand-side of the equation. Reducing water demand and incorporating con-

servation measures in water management may be the only economically feasible way to achieve a sustainable water future.

Sources:

Postel, S., 1986, ***Increasing Water Efficiency***, State of the World, 1986, L. R. Brown et al. (Editors), W. W. Norton and Company, New York, New York.

Dry Hydrants

With the increasing demand for drinking water for a growing human population (as well as suburban areas increasing in number and expanding into previously rural areas), dry fire hydrants may be a practical and cost effective way to provide fire protection to certain areas.

Dry hydrants look like regular pressurized fire hydrants. The difference is that instead of being hooked to a drinking water main, they are piped to a pond, lake, stream or other water source. When needed, a firefighting truck pumps water through a pressurized suction hose from the hydrant that is linked to the pond by buried pipes. These are especially effective during the winter when the water source may be frozen. If a dry hydrant is not installed and the water source is frozen a tradition pumping truck would have to pull up to the water source, and then someone would have to cut into the ice to reach the water, which would take precious time during a fire situation.

Especially in southeast Missouri, another advantage of dry hydrants is they're earthquake-proof. Were an earthquake to occur, causing breaks in water supply lines, dry hydrants would have less detrimental impact upon the public water supply system because they are not hooked into that system, and therefore can not cause a loss of water pressure from water main ruptures. It is also possible that a water line would be ruptured, and there would be no water to fight the fire with. This is especially important because earthquakes often cause fires to start.

Dry hydrants generally have less expensive initial installation costs and lower operation and maintenance costs than wet hydrants that are hooked to the public water supply water mains. Dry hydrants are not feasible for all areas and all conditions, but where adequate quantities of reliable surface or groundwater exist, dry hydrants are a viable option.

Rainwater Capture

In areas with insufficient potable groundwater resources (e.g. St. Francois Mountains or the Osage Plains), capturing and storing rainwater provides an alternative water supply. Often this is done in the form of a dammed drainage area to form a reservoir. However, this may be too expensive for an individual household, or not possible due to the local geology, or the landowner might not have enough or the right property (i.e. they own only bottomland) for such a pond.

Rain harvesting is a time-tested method that may be a viable alternative in some locations, particularly remote ones. This involves capturing and storing the rain that falls on a roof. Usually, this is done by having gutters direct the water into some sort of cistern or other large container for storage (note: there have been significant improvements in cisterns and container technology over the past 75 years). The Texas Water Development Board has published a technical bulletin discussing the hows and whys of rainwater harvesting, including many case studies (TWDB and CMPBS, 1997). It appears it is often a safe, sufficient and economically viable water supply in many situations.

Rainwater harvesting can have the extra benefit of mitigating stormwater runoff problems in developments. For example, if all the houses in a subdivision had some form of rainwater capture, it would decrease the stormwater runoff and its associated problems. In addition, this stored water could then be used for watering lawns, which turns out to consume large quantities of water throughout the warm season, thereby decreasing the amount of drinking water used for irrigation.

Sources:

Texas Water Development Board (TWDB) and the Center for Maximum Potential Building Systems (CMPBS), 1997, ***Texas guide to rainwater harvesting***, found online at: www.twdb.state.tx.us/assistance/conservation/Rain.htm

Bootheel Area Multifunctional Wetlands

Landowners in southeastern Missouri, blessed with abundant water supplies, gentle topography, and a mild climate, could take advantage of opportunities to grow rice crops in the summer and keep water on the land in fall, winter, and spring months for additional purposes.

Some farmers who now raise rice in the Bootheel region of the state already have experimented with keeping water on their lands after rice harvest, through the winter, and before spring planting.

One farmer in Stoddard County, for example, after combining his rice crop, goes over the fields with a heavy roller, breaking (or bending) rice stalks down so that they will be submerged when he re-floods his fields. The flooded fields then become habitat for various species of macroinvertebrates that are food for migratory waterfowl. Rails, which like muddy shoreline habitat; puddle ducks, which like shallow water for "dipping," and diving ducks, which like deep water, all have a chance to rest and forage on their way south toward Louisiana for the winter months.

Again, in the spring, the farmer manipulates the water level in his fields to accommodate the schedules of the northward migrating waterfowl species, so that there are muddy, marginal areas, shallow water areas, and deep water areas to the liking of the different species of birds. When the migration is done, it is time for planting another year's crop of rice. The manipulation of water levels is done by means of existing pumps and weirs that he uses in his rice-growing operation during the warm months of the year.

There are obvious wildlife habitat benefits to the above mentioned practice, but also this increases the potential of other revenue generation. Some farmers build “blinds” for watching, photography, or hunting, adjacent to their fields, and go out hunting during the migratory waterfowl season. Others even rent hunting blinds to folks who have no rice fields of their own, earning a little extra cash in the off-season. The presence of the water also draws other wildlife to the wetlands, such as deer. Many farmers harvest venison as a crop in season, to augment their meat supplies. Some maintain

the “wetlands” for aesthetic reasons. Many land-owners like to see the migratory waterfowl stopping by during fall and winter travels. They like the sight and sound of the migrating water fowl and song birds.

Sources:

Gaffney, Richard M., Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, 2002.



Comments Received

Topics in Water Use: Southern Missouri was reviewed by various staff in the division at several stages of preparation. The Interagency Task Force made comments and then the draft report was placed on the Department of Natural Resources' Geological Survey and Resource Assessment Division's Internet web page for access and comment by the public. This request for comment was issued in a statewide newsrelease. The public comment period was 30 days on this report.

The draft report was accessed only three times during the comment period.

The following comments were received from a geologist that has statewide groundwater experience. The comments are of a detailed theoretical nature concerning the movement of groundwater over geologic time and resultant quality of groundwater. While these comments are good issues to consider relating to management of our water resources in southern Missouri, this planning document was not intended to address detailed geologic theories. We do appreciate the time spent on preparing these comments, the publications referenced for additional information and the need expressed to consider alternative sources of drinking water in the region. The comments are reproduced as received.

Comment: "As far as I know, this is the first DNR document to admit groundwater mining is occurring in Southern Missouri. The authors are to be commended. However, this document fails to address THE first order question in the southern Missouri water situation, namely: "Why does the deep Ozark Aquifer contain saline water in some areas and freshwater in other areas?" If this question is not scientifically addressed, higher truths will remain elusive. The answer can be found in a USGS publication pre-

pared in cooperation with the Geological Survey of Missouri:

Equivalent freshwater head and dissolved-solids concentration of water in rocks of Cambrian, Ordovician, and Mississippian age in northern Mid-continent, U.S.A., by Jorgensen, D.G., Helgesen, J.O., Leonard, R.B., and Signor, D.C., 1985, Geological Survey Miscellaneous Field Studies Map MF-1835-B, scale 1:1,000,000, 2 sheets.

According to Jorgensen et al., the explanation for the salinity concentrations found in mid-continent groundwater is that in the geologic past "...water flowed from east to west under different geologic and hydrologic conditions." The unfortunate consequence of this reality is that large parts of the confined Ozark Aquifer in western Missouri (and northeastern Missouri) lack a real recharge area. Having no recharge area is bad. The situation is graphically illustrated on the worldwide web in a recent report by Wittman Hydro Planning Associates. The reports are attached to this e-mail. Wittman Hydro Planning Associates break with a long tradition of egregiously bad science: namely the practice of ignoring the groundwater divide that separates the Mississippi Basin and Arkansas Basin. This groundwater divide effectively separates the deep, western Missouri Ozark Aquifer from its former recharge areas in the Salem Plateau region. Research done since 1985 has reinforced the conclusion reached by Jorgensen, et al. Most notably, the relative lack of tritium in highly productive Ozark Aquifer wells, meaning the groundwater is old. See USGS WRI 00-4038. Microbiological and chemical quality of ground water used as a source of public supply in southern Missouri; phase I, May 1997-March 1998, by J.V. Davis and E.C. Witt, III. 2000. 77 p.

Specific comments

On pages 14 and 15, the Draft states
‘.....This part of the southwestern region (Osage Plains) coincides with the freshwater-saline water transition zone. Therefore, the deeper Springfield Plateau aquifer and the Ozark Aquifer contain water too highly mineralized for use.’

This section implies that the freshwater-saline water transition zone coincides with the eastern border of the Osage Plains, apparently endorsing the popular notion that salinity in the Ozark Aquifer is somehow related to the presence or absence of Pennsylvanian-age shale. This notion does not stand up to scrutiny. In reality, the freshwater-saline water transition zone does NOT coincide with the eastern border of the Osage Plains. Vernon County and Johnson County are virtually covered with Pennsylvanian-age shale. Yet both counties enjoy huge freshwater supplies in the deeply buried Ozark Aquifer, despite their location on the Osage Plains. Meanwhile, on the opposite side of the state in Jefferson County and Cape Girardeau County, significant salinity is encountered within the Ozark Aquifer, despite the virtual absence of Pennsylvanian-age shale. Again, the real reason for the current position of freshwater-saline water transition zone is that the position of groundwater divides has migrated within the recent geologic past.

On Page 29, the draft states that:

“....If there is ample time between pumping cycles, the well will fully recover and water level will return to its pre-pumping level.”

The treatment of aquifer overexploitation in the draft focuses on water levels and ignores the very real and irreversible deterioration due to the resulting saline groundwater intrusion. The eastward encroachment of saline groundwater along the freshwater-saline water transition zone has been documented in Water resources of west-central Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-491 by Gann, E.E., Harvey, E.J., Barks, J.M., Fuller, D.L., and Miller, D.E., 1974.

On Page 30, the draft states that:

..... (groundwater is a) resource that is ultimately replenished by precipitation soaking into the earth. Each water well has a source-water area that supplies it. Depending on geology and well construction, some wells receive their recharge entirely from infiltration of precipitation.

In reality, many water wells (for all practical purposes) lack a real recharge area. Many water wells in western Missouri have no source-water area. These include wells used by the cities of Noel and Joplin. The areas that lack recharge are generally depicted on Figure 9 in USGS WRI 00-4038, Microbiological and chemical quality of ground water used as a source of public supply in southern Missouri; phase I, May 1997-March 1998, by J. V. Davis and E. C. Witt, III. 2000. 77 p. Areas that are west of the main Ozark groundwater divide and designated as aquifer type C(OzCu) an C(W) on Fig. 9 should begin to protect and eventually develop surface water sources.